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LEVERAGING NATIONAL OCEANOGRAPHIC CAPABILITIES

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EARING

THE

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT OF THE COMMITTEE ON SCIENCE

AND THE

SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT OF THE COMMITTEE ON NATIONAL SECURITY

AND THE

SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS OF THE COMMITTEE ON RESOURCES

U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTH CONGRESS

SECOND SESSION

JANUARY 25, 1996

[No. 69]
(Committee on Science)

[H.N.S.C. No. 104-34]
(Committee on National Security)

[No. HJ-1]
(Committee on Resources)

Printed for the use of the Committee on Science, the Committee on National Security, and the Committee on Resources

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JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
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JOINT HEARING ON LEVERAGING NATIONAL OCEANOGRAPHIC CAPABILITIES

THURSDAY, JANUARY 25, 1996

U.S. HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE, SUBCOMMITTEE ON ENERGY AND ENVIRONMENT, COMMITTEE ON NATIONAL SECURITY, SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT, AND COMMITTEE ON RESOURCES, SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS

Washington, DC.

The Subcommittees met at 10:00 a.m., in Room 2318 of the Rayburn House Office Building, the Honorable Curt Weldon, Chairman of the Military Research and Development Subcommittee of the Committee on National Security, presiding.

Mr. WELDON. Good morning.

This morning, it gives me great pleasure to join my colleagues, Congressman Saxton and Rohrabacher, to co-chair this landmark hearing between the National Security Committee's Subcommittee on Research and Development, the Fisheries, Wildlife and Oceans Subcommittee of the House Resources Committee, and the Energy and Environment Subcommittee of the House Science Committee.

I apologize for the room. We were originally going to have this in the larger 2118, where we could have accommodated everyone with seats and, hopefully, we've be able to ultimately do that, but because of a Bosnia hearing later on, we had to move it to this room, which is a fine room, except it doesn't have as much seating.

So we hope we can accommodate everyone.

I believe this is a landmark hearing which I believe will help set the agenda for oceanography throughout the next decade. Today, we have successfully brought together our nation's leading scientific experts from government, industry, and academia, in an effort to lay the groundwork for renewal and resurgence of oceanography in America.

Let me say at the outset that we have broad-based support on this initiative going in. I include for the record a letter from Al Gore to me, which he sent to me in December prior to this series of hearings on oceanography issues of the National Security Committee, and also a letter from the leader in the Senate, Trent Lott, who has indicated his wholehearted support for not only this hearing, but our renewed focus on oceanography.

So both from the Administration and the other body, we are getting public signs that there is strong interest in our agenda for 1996, relative to the oceans.

We're all anxious to hear from our panelists, but I'd like to make a few opening comments.

First, I'd like to draw attention to the state of the world's oceans from an international perspective before we look to the future of oceanography in the U.S.

And to that end, I would suggest to our colleagues that have not read Sylvia Earle's book, "Sea Change," that they do so, because perhaps it sets the tone for the need for us to aggressively look at a new focus on the oceans in 1996 and beyond.

I recently returned this past weekend from Russia, where I visited both Moscow and St. Petersburg, in Moscow delivering a landmark letter from Speaker Gingrich to the new speaker of the Russian Duma, Mr. Soleviev, where we advocated setting up a direct Duma-to-Congress forum similar to our Congress-Bundestag forum where member of Congress can interact with the Duma on a variety of issues.

One of the leading issues that will take precedence in that new process is the environment, and one of the subgroups will be the oceans.

In addition, we also in that letter asked the speaker of the Russian Duma to establish a direct Internet linkage between members of Congress and the Duma so that we can break down the barriers of communication and communicate directly with leaders, not just of the Russian Duma, but the other major parliaments of the world, on issues involving security, energy, other major concerns, but certainly the oceans and the environment.

In St. Petersburg, I was able to participate in a conference on the protection of Russian's northern Arctic environment. The conference was hosted by the Advisory Committee on the Protection of the Seas—ACOPS—for which I serve as the United States Vice President.

This meeting was a follow-up to a hearing we held in December in this Congress, where Alexia Yoblakof, one of the leading environmentalists in Russia, and Kara Brynn, the foreign minister for the environment from Norway, spoke before our subcommittees on the problems of the Arctic environment, and particularly how we're assisting them through the Department of Defense in dealing with the terrible problem of dumped nuclear waste.

While this particular conference focused on one specific area of concern, I had the opportunity to discuss the overall health of our ocean environment with other legislators from around the world, including members of the Russian Duma, the Japanese Diet, and the European Parliament.

It is clear that there is an international commitment to ensuring the health and ecological balance of our world's oceans. So it is timely that we gather here today to revive our nation's commitment to ocean research and to discuss ways to more effectively focus our efforts.

Not since the Presidential Stratton Commission on revitalization of oceanography over 25 years ago, has there been this degree of interest and attention to the importance of ocean research.

As Chairman of the Research and Development Subcommittee of the House National Security Committee, which oversees $35 billion a year of military research and development, much of it going to study the oceans, I'm very concerned about what we know about the oceans as a matter of national defense and security.

On the other hand, through my affiliation with ACOPS and my position as Chairman of the Oceans Task Force of GLOBE USA—Global Legislators for a Balanced Environment—I am also concerned with ocean research from an environmental standpoint.

We're going to combine the two, even to a greater extent than has been done in the past.

We know much about the oceans, but at the same time, we know very little. Within the scientific community and certainly now in the Department of Defense, we have the latest powerful supercomputers, sensors and analytical tools that can unravel the oceans' secrets to further aid and strengthen our defense, understand world weather problems, predict sea life behavior, protect the environment, and develop the potential to generate new, improved industries that rely on the oceans.

As a maritime nation, we should be concerned about our ability to defend our maritime territories and maintain our ability to control the seas in wartime.

As citizens and legislators, we are also concerned about our shores and ocean economic zones. In particular, we should focus on: finding reasons for the decline of world-wide fisheries; understanding our paucity of ocean industrial endeavors; maintaining the environmental health of our oceans and tributaries; and exploring ways to prevent certain countries from continuing to use the oceans as a dumping ground for nuclear and other toxic wastes.

To this end, in the spring of last year, Senator Kerry and I cohosted an international forum on the oceans on the Senate side, where we had 200 leading experts from around the country come to this city to talk about these and other issues.

Therefore, we in the Congress have a responsibility to ensure that ocean research continues and that there is a way to refocus it, improve technology transfer, and cooperate with partnerships to make it more productive and effective to meet the needs of our community.

This is what this initiative is all about.

It's about refocusing—setting a meaningful agenda that meets the needs of national defense, other public good, and our industry, large and small.

It's about efficiency—working smarter, more efficiently in harmony and communication through partnering arrangements.

And it's about dual-use—expanding the world that we do for defense into a synergistic leveraging mechanism for both defense and civilian applications.

So we have gathered our panelists here today to hear their thoughts about the best way to turn this initiative into reality. It is through their expertise that we can determine ways that government agencies and departments can leverage their oceanographic resources through partnership relationships.

In addition, we will supplement this hearing with a series of briefings to be held around the country, to hear from developers and users of ocean technology at the regional level.

Our first briefing, which was held last Monday at the Naval War College in Newport, Rhode Island, successfully brought together a diverse group who have developed their own regional partnerships. We had the opportunity to hear what is working and what isn't in Newport.

Throughout the year, we will continue to hear from those in the oceanographic community who have implemented innovative partnerships to more effectively utilize oceanographic resources.

This spring, we will reconvene back here in Washington and examine what is really working out in the field.

We are embarking on a bold and exciting new adventure, which, in my opinion, will shape the debate about ocean research for at least the next decade.

Hopefully, historians will remember 1996 as the Year of the Oceans in America, and eventually, the world, as we prepare for the major Oceans International Exposition coming up in Lisbon, Portugal in 1998.

[The prepared statement of Chairman Weldon follows:]

STATEMENT OF CHAIRMAN CURT WELDON

JANUARY 25, 1996

JOINT HEARING ON LEVERAGING OCEANOGRAPHIC CAPABILITIES

MILITARY RESEARCH & DEVELOPMENT SUBCOMMITTEE

HOUSE NATIONAL SECURITY COMMITTEE

FISHERIES, WILDLIFE, & OCEANS SUBCOMMITTEE

HOUSE RESOURCES COMMITTEE

ENERGY AND ENVIRONMENT SUBCOMMITTEE

HOUSE SCIENCE COMMITTEE

This morning it gives me great pleasure to join my colleagues, Congressmen Saxton and Rohrabacher, to co-chair this landmark hearing which I believe will set the agenda for oceanography throughout the next decade. Today, we have successfully brought together our nation's leading scientific experts from government, industry, and academia in an effort to lay the groundwork for a renewal and resurgence of oceanography in Americaa.

I am anxious to hear from our distinguished panelists, so I will keep my comments short. However, I would like to make a few opening remarks before we begin.

First, I would like to draw attention to the state of our world's oceans from an international perspective before we look at the future of oceanography in the United States. I recently returned from St. Petersburg, Russia where I participated in a conference on the Protection of Russia's Northern and Arctic Environment. The conference was hosted by the Advisory Committee on the Protection of the Sea (ACOPS) for which I serve as the United States Vice President.

While this particular conference focused on one specific area of concern, I had the opportunity to discuss the overall health of our ocean environment with other legislators from around the world, namely members of the Russian Duma, Japanese Diet, and European Parliament. It is clear that there is an international commitment to ensuring the health and ecological balance of our world's oceans. So it is timely that we gather here today to revive our nation's commitment to ocean research and to discuss ways to more effectively focus our efforts.

Not since the Presidential Stratton Commission on revitalization of oceanography, over 25 years ago, has there been this degree of interest and attention to the importance of ocean research. As Chairman of the Research and Development Subcommittee of the House National Security Committee, I am very concerned about what we know about the oceans as a matter of national defense. On the other hand, through my affiliation with ACOPS and my position as Chairman of the Oceans Task Force of GLOBE USA (Global Legislators for a Balanced Environment), I am also concerned with ocean research from an environmental standpoint.

We know much about the oceans but at the same time, we know very little. Within the scientific community and certainly now in the Department of Defense, we have the latest powerful super computers, sensors and analytical tools that can unravel the oceans secrets to further aid and strengthen our defense, understand world weather problems, predict sea life behavior, protect the environment, and develop the potential to generate new improved industries that rely on the oceans.

As a maritime nation, we should be concerned about our ability to defend our maritime territories and maintain our ability to control the seas in wartime. As citizens and legislators, we are also concerned about our shores and ocean economic zones. In particular, we should focus on: finding reasons for the decline of worldwide fisheries; understanding our paucity of ocean industrial endeavors; maintaining the environmental health of our oceans and tributaries; and exploring ways to prevent certain countries from continuing to use the oceans as a dumping ground for nuclear and other toxic wastes.

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- It's about refocusing,—setting a meaningful agenda that meets the needs of national defense, other public good, and our industry, large and small.
- It's about efficiency,—working smarter more efficiently in harmony and communication through partnering arrangements.
- It's about dual use,—expanding the work that we do for defense into a synergistic leveraging mechanism for both defense and civilian applications.

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We are embarking on a bold and exciting new initiative which in my opinion will shape the debate about ocean research for the next decade. So I am now anxious to hear from the experts.

Mr. WELDON. At this point in time, I'd like to recognize a distinguished leader on ocean issues, whose breadth and scope of environmental concerns is unparalleled by anyone in this Congress, the distinguished chairman of the Fisheries, Wildlife and Oceans Subcommittee of the House Resources Committee, Mr. Jim Saxton.

Mr. SAXTON. Thank you very much, Mr. Chairman, for the opportunity to be here today.

I am pleased that the three subcommittees are meeting today to begin a complete review of the Federal Government's oceanography program.

No such comprehensive review has been undertaken in more than 20 years, and that lack of oversight has kept oceanography funding from keeping pace with the overall U.S. research funding programs.

The primary interest of our subcommittee, the Subcommittee, as you just mentioned, Mr. Chairman, on Fish, Wildlife, and Oceans, is the National Oceanic and Atmospheric Administration. The agency conducts both basic oceanographic research and research that is focused on providing assistance to the agency's management and operational programs.

One of the primary issues NOAA is now facing is how to continue to gather the data necessary to carry out the agency's functions with its aging and dwindling research fleet.

I hope these hearings will give us the information necessary to make decisions about the future of NOAA as a ship-owning and operating-agency. I also hope these hearings will lead to a higher profile for NOAA's ocean and coastal programs within the agency, and to better integration of NOAA's programs with those of the Navy and the National Science Foundation.

We truly have an impressive group of witnesses here today, and I thank all of you for coming and look forward to your testimony.

Mr. WELDON. Thank you, Mr. Saxton. I'd like to also ask for opening welcomes from the actual host for our hearing today. I'm a member of his subcommittee, besides chairing the R&D subcommittee for security, a distinguished colleague and a friend and an activist on the Science Committee and in this Congress, Dana Rohrabacher from California, who chairs the Energy and Environment Subcommittee for the House Science Committee.

Mr. ROHRABACHER. Thank you, Chairman Weldon.

First of all, I'd like to note that I come from a coastal district and Chairman Weldon does not come from a coastal district. He's from a land-locked district. I'd like to commend him for being from a land-locked district, yet having an incredible interest, an overriding interest in ocean research and what we do and how we relate to this part of the planet, this majority part of the planet.

I want to also commend you, Chairman Weldon, for these hearings today. This is an important step in raising the awareness of this Congress, as well as the public, to the importance of ocean research.

I am well aware of the Chairman's dedication because, as you've just said, Mr. Chairman, you are also a member of the Energy and Environment Subcommittee, of which I chair.

This is a timely hearing and our choices are not going to get any easier as we move towards a balanced budget. The choices we are going to have to make are going to be tougher and tougher, and that includes the choices that we're making in terms of oceanographic research.

We have to set priorities in all areas of scientific research to make sure that we get the best use out of all available funds.

For example, the questions we have to ask, what priority do we place on basic research in oceanographic research, as compared, for example, to commercial development, such as marine parks? Other questions—how can the government and the university community make better use of private-sector dollars in research projects?

We will also hear today from top civilian and defense policy-makers on the potential of dual-use technologies. I'm very excited about that and very interested in that area. I think that not only will dual-use technologies in this area be very beneficial to our country, but also in other areas. And I'm very happy that Chairman Weldon is drawing attention to those today in terms of the area of oceanographic research and dual-use technologies in that area.

And we need to find out, consistent with that, how civilian agencies can work with defense-related agencies in order to unlock the mysteries of the sea. There's a lot that government can learn from itself. Not only can we have public/private sector partnerships, but different agencies in government should work together.

As a congressman from a coastal district, I do take this hearing very seriously. I spend a lot of time in the water, in the ocean, and I'm keenly aware of the importance of oceanographic research.

I believe we can fill this need, however, without the massive infusion of new federal funds, basically with streamlining and consolidating programs, more involvement of the private sector and lowering the barriers of dual-use technology, as Chairman Weldon has mentioned.

So I applaud you, Mr. Chairman, for your dedication on this issue and look forward to our two subcommittees working together on this area of shared jurisdiction.

Thank you.

Mr. WELDON. Thank you, Mr. Rohrabacher. And as you can see, we have three subcommittees, so three chairmen acting today. We have three very distinguished and capable ranking members. It is an extreme pleasure for me to ask for his opening comments, our leading Ranking Member who is present today, who has been a dynamic leader in the Congress on environmental issues and is a good friend and someone who I have the highest respect for, Mr. Tim Roemer.

Mr. ROEMER. Thank you, Mr. Chairman. I'm delighted to be here. My voice did not accompany me this morning, so I will be brief. I will ask unanimous consent to submit my opening statement and just make some brief remarks.

First of all, I'd just like to say that we have a distinguished gathering of our subcommittees this morning. In an almost historic way, we have an equally distinguished panel that I am very much looking forward to hearing your expertise and your testimony on some very important subjects here this morning.

As we talk in the United States Government today, Democrats and Republicans, about downsizing government and balancing the budget, both of which I support, the question becomes not when we do it, but how we do it, and how we include the expertise of people at this panel to help us make some very difficult decisions about some very important research that is going on in our oceans.

Now just as we've just gleaned tremendous results and successes from the Galileo and Hubble experiments in space, I think we have equally spectacular possibilities of success in our oceans.

So I'm hopeful that we can do this in a cooperative way, a way by which we enhance our ability to glean resources together in the most efficient manner, that we have possibilities to put our resources together in such capital funding areas which are so expensive for satellites and ocean vessels, which will need cooperation between our different agencies if we're going to see cuts, that we see a prudent policy put forward in terms of declassification of information, and that we also see a coordination not just of our committees here this morning, but of our agencies out there represented by this distinguished panel.

I'm very excited about the possibilities here this morning, about the information that we'll glean from this panel, and I hope that we will take to hear your information and not just set arbitrary levels to cut at 25 or 33 or 40 percent, but find ways by which we can put agencies together in more creative and innovative ways so that we do not hurt the important research that will take place in such a vital area as our oceans.

With that, Mr. Chairman, I yield back the balance of my time, or because maybe I'm the only Ranking Member here that's represented, I would ask you that Mr. Rohrabacher and I, can we get our budget tripled by the lack of representation from the other committees.

[Laughter.]

[The prepared statement of Congressman Roemer follows:]

OPENING STATEMENT, REP. TIM ROEMER, HEARING ON LEVERAGING NATIONAL OCEANOGRAPHIC CAPABILITIES, THURSDAY, JANUARY 25, 1996

Mr. Chairman, oceanography is a broad term that encompasses all research addressing the structure, dynamics and ecosystems of oceanic and coastal zone areas. It involves many disciplines: chemists follow the chemistry of the open ocean and the shores; physicists chart the fluid dynamics of the ocean which have great effect of weather patterns; geologists chart the topography of "land under water"; biologists investigate ocean life; and engineers design the tools they all need to conduct this research.

As a result, federal oceanography support comes from a diverse category of agencies, from science to military to intelligence to environmental. This diversity frequently has not been a benefit to the oceanographic community. It is difficult to form partnerships, keep them funded, fairly disseminate information, maintain expensive equipment, and further the goals of our oceanographic research community.

With a shrinking federal budget that is causing rapid reductions in federal investment in research and development, we need to know what the impact will be on important programs such as oceanography. What will the private sector be able to pick up? What is the proper role of the university community? Who has the resources to support the expensive capital funding required for research, to support the research vessels and whole ocean experiments?

These questions are critical not only because of the shrinking budget, but because of changing priorities within the U.S. military. The end of the Cold War has meant that much of the Navy's Oceanographic study will be discontinued. Major hardware will be retired. A great resource will cease to exist. Although the Navy is working to declassify much of the information they hold—superior information—the future of these other assets is in doubt.

The answer to continued quality oceanic research in times of rapidly shrinking budgets might seem to be cooperation and sharing of resources among concerned agencies. But the result in this field has been just the opposite. Oceanic research is simply not the highest priority for many of these agencies, and partnerships are being dissolved in the middle of data collection phases, and data from such projects permanently lost. Joint agency commitments to oceanographic research are difficult to maintain in strict budget times, and critical research opportunities fall through the cracks, and some may be irretrievable.

The course for downsizing in a way that cuts unnecessary spending but preserving needed research is a decidedly tricky one, and we need a concrete planning effort to achieve one that will succeed. While I am pleased to learn more about the scientific history and potential of our oceanographic infrastructure and what value it has to our nation and its people, it is my hope to also address the larger budget questions that affect such R&D, and how these witnesses feel that our budget problems will affect this necessary and important research.

Mr. WELDON. We can work on a deal.

Mr. ROEMER. All right.

[Laughter.]

Mr. WELDON. Thank you, Mr. Roemer, for those excellent statements and comments and we look forward to your leadership on the Democratic side.

I'd like to ask our colleagues from Virginia or Maryland if they like to make opening statements?

Mr. Gilchrist or Mr. Bateman?

Mr. GILCHRIST. I'd just say something very quick since Mr. Roemer mentioned something about the space programs and how we need to coordinate.

I suppose if all of us, or some of us, were in a space shuttle going out to space and we represented—one person represented the science community, one person represented the government, one person represented the private sector or whatever, that they probably wouldn't craw into each other's corner on the space shuttle. As they traveled through this hostile environment, they would work together to preserve the few resources they had so that they could survive their trip back to earth.

And I think, to a large extent, the planet earth is in that same infinite, hostile environment. And so it's encumbent upon each of us—the scientists, the military, the private sector, the elected officials, to take the responsibility to contribute as much time, energy and expertise as they can muster to protect what in essence the blood of life in the human body and the water on the planet are the same thing.

So I look forward to these hearings and I thank the gentleman from Pennsylvania, who may not live in a coastal district, but his district certainly impacts my district because water runs downhill——

[Laughter.]

Mr. GILCHRIST. (continuing) for calling on this hearing.

Mr. WELDON. I thank my friend and colleague.

Mr. Kennedy?

Mr. KENNEDY. Thank you, Mr. Chairman.

As most of you know who have watched the news as of late, my state is suffering from a terrible oil spill in Rhode Island. We know first-hand about the importance of studying the ocean so that we can better predict current flows, the impacts of environmental degradation and pollution, how this manifests itself in the shell-fishing industry, the tourism industry.

It's just been an awful reminder in our state as to how precious our natural resources are when something like this happens.

I can tell you from our hearing on Monday, Mr. Chairman, where you came up to Rhode Island and we had a hearing at the Naval War College, much of the research that's going on currently within the Department of the Navy to research our literal environment, the coastal zone, can have great application in studying the environmental aspects of the coastal zone.

And what we're interested in our state is to take the great knowledge base that comes from having the Naval Undersea Warfare Center in our state and the University of Rhode Island, which is pre-eminent in the universities around the country in its study of marine sciences, take the synergy that can come from the two of those and put it to good use in protecting our coastal zone.

It's already come in handy with this latest oil spill in helping to predict where the oil flow is going and helping to boom off those areas that are most sensitive.

But I want to add, Mr. Chairman, that I appreciate the opportunity to hear the panelists today and I have some other comments and questions later on that I look forward to asking.

Mr. WELDON. Thank you, Mr. Kennedy.

Ms. Johnson or Mr. Meehan, do either of you have opening statements you'd like to make? Thank you both for attending.

Would you like to make an opening statement?

Ms. JOHNSON. Just a short one. I want to first express my appreciation for bringing the three committees together to have this hearing and to thank this most distinguished panel for being here. I look forward to hearing from you.

I'm from Dallas, Texas, and the only ocean we have is the Trinity River.

[Laughter.]

But I would like most of you, if you could, to comment on the public/private partnerships and other types of research as well as you give your testimony.

I would hate to miss this opportunity with such a distinguished panel because I'm very, very supportive and strongly interested in the public/private partnerships in research and development.

So I thank you very much.

[The prepared statement of Congresswoman Johnson follows:]

OPENING STATEMENT

THE HONORABLE EDDIE BERNICE JOHNSON

JOINT HEARING ON OCEANOGRAPHY

25 JANUARY 1996

Thank you, Mr. Chairman.

With the changes taking place in the Department of Defense regarding the sharing of information about the ocean, we now have a clear opportunity to learn more about the role the ocean plays in such fields as energy production.

I look forward to the testimony today concerning basic and applied research in the field of oceanography. I hope the witnesses can comment on energy opportunities that could flow from this research.

Looking at the quality of the witnesses that will testify before us today, I would also ask that the witnesses comment in general terms about the research and development policy of the Nation in fields other than oceanography. It has been a prime concern of many of us on the Committee on Science that the Nation's investment in research and public-private partnerships is declining at a time when the Nation needs to commit itself to advancing our technology. Perhaps some of our witnesses could comment on our needs in these areas.

I commend all three of the Committees involved here today for holding this hearing, and I look forward to receiving the testimony of our most distinguished panel.

Mr. WELDON. Thank you, Ms. Johnson. And before we proceed with our distinguished panel, I've asked the host/chairman if he would mind, if staff wants to sit in the first row, they can feel free to do so, and that would then free up some seats for those who are currently standing in the back.

So any of you who are staff who would like to move out of seats and move up into here, you're welcomed to do that, and that would then free up some other seats.

Our panel today is certainly a distinguished panel. And as I said, this is certainly a landmark hearing.

We will start with Doctor—and I'll introduce each of them, then we'll have the entire panel proceed, and then we'll open it up for questions:

Dr. Robert Ballard is senior scientist and director of the Center of Marine Exploration at the Woods Hole Oceanographic Institute. He will be our first witness.

Dr. Bruce Alberts, president of the National Academy of Sciences, will be our second witness.

Dr. Neal Lane, director of the National Science Foundation, will be our third witness.

Dr. James Baker, administrator of the National Oceanic and Atmospheric Administration, will be our fourth witness.

Admiral Jeremy Boorda, USN, chief of naval operations, Department of the Navy, will be our fifth witness. He is on his way here. His plane just landed. He will be here shortly.

Rear Admiral Paul Gaffney, commander of the Navy, Meteorological and Oceanographic Command at the Stennis Space Center, will be our sixth witness.

Dr. Robert Frosch, Center for Science and International Affairs, the John F. Kennedy School at Harvard University, will be our seventh witness.

And batting clean-up today, and certainly someone who needs little introduction, a good friend, Admiral Jim Watkins [retired], who is the director of the Consortium for Oceanographic Research and Education.

We're pleased and proud to have all of you here. And with that, Dr. Ballard, we will welcome you and we will accept your statement for the record and would invite you to make whatever comments you'd like so that we can get into the questions.

Dr. Ballard?

STATEMENT OF DR. ROBERT D. BALLARD, SENIOR SCIENTIST DIRECTOR, CENTER OF MARINE EXPLORATION, WOODS HOLE OCEANOGRAPHIC INSTITUTION

Dr. BALLARD. Mr. Chairman, I'd like to divide the time I've been given to a formal presentation and then leave as much as possible to questions you may want to ask of myself and other members of our panel.

I've already submitted a lengthy version of my testimony, which I will now attempt to summarize.

Modern research now suggests that all humans on the face of our planet have come from a common heritage that can be traced back to the eastern plains of Africa, and that during the last 200,000 years, our ancestors have journeyed forth from their birthplace to populate the planet.

Now many factors have led to the global expansion of our forefathers. For one reason or another, the fact remains, our species now dominates the planet, having conquered many of the forces that held us in check for oh so many millenniums.

Instead of being controlled by the forces of nature, we are now beginning to alter nature itself.

Some demographers now tell us that there are more humans alive today than have ever died since the beginning of our species. And what took us 200,000 years to reach, we will double again as we struggle through just the next century.

Despite the rhetoric about the need to control the population, we continue to multiply, entering an era where reproduction is now endangering our existing instead of ensuring our survival.

But I am not here today to talk about controlling the world's population. I'm simply an underwater explorer who has spent the last

30 years of my professional career beneath the sea exploring its many wonders. And I would like to take the next few minutes that I have to tell you about what I've seen and to try to guess what I think the future might hold for us, given the clear fact of our continuing growth and the need of our peoples for more space and resources.

Despite our globe-trotting abilities, our species has not colonized any new land masses on the planet since the colonization of the new world, which began in the 15th century.

Today, the primary activities of our species is still confined to less than 25 percent of the planet, historically held at bay by the aquatic world that has resisted our colonizing ways.

Ironically, instead of turning to the sea for our future, we have, and I believe in many ways, validly turned our eyes to the heavens, convinced that maybe the future lay in space.

Perhaps some day that will come. But I am convinced not in time to save us from the path that we find ourselves on right now.

I want to make you understand that I am a strong supporter of the space program. In fact, as an oceanographer, I've been envious of their ability to bring together science, industry, and academia to work together in a common path. And I hope that one of the byproducts of this hearing will bring the community that sits behind me together as much as the committees in front of me.

But I find it ironic that humans have lived in space now for longer periods of time than they've ever lived underwater. In fact, recent congressional action is forcing us to abandon our only underwater research facility where scientists are able to live beneath the sea for extended periods of time.

Isn't it interesting that Congress has been funding studies to look at potential colonization of the moon, but we've never, to my knowledge, initiated a study on how we might colonize the oceans.

To me, the most important image to come out of the space program was when an astronaut on his way to the moon trained his cameras back over his shoulder and captured an image of a very small, greenish-blue planet embedded in a black velvet void of nothingness.

Ironically, we have good topographic maps now of the far side of the moon, of its volcanic craters, than similar features in our own exclusive economic zone just off our shores.

When President Reagan signed the law creating the exclusive economic zone, the size of America doubled. Yet, most of this modern-day Louisiana Purchase remains unexplored. The largest single feature on the surface of the planet is the Mid-Ocean Ridge, which covers a quarter of the planet's total surface area. Yet, despite its tremendous size and the critical role this mountain range plays in the origin of the earth's outer skin, Neil Armstrong walked on the moon before the first human beings entered the largest feature on earth, when they dove to the rift valley of the Mid-Ocean Ridge in 1973.

Few people realize that there are more active volcanoes underwater than on land, or know of the great plains that dwarf those in America, or of the canyons that are far greater than the Grand Canyon, or that the mighty Rocky Mountains would fit into a small portion of the Mid-Ocean Ridge.

Given the emergence of advanced robotic technology, fiber-optics, micro-processors, autonomous vehicles, telecommunications, and many other new advances, the oceans will no longer be a barrier of human activity.

Given our exploding population and given the continued development of advanced technology, I truly believe the 21st century will usher in an explosion of human activity in the sea.

I am convinced that the next generation will explore more of earth—that is, the 71 percent that's underwater—than all previous generations combined.

And just as Lewis and Clark's exploration of the Louisiana Purchase led to the settling of the west, the exploration of the sea will lead to its subsequent colonization.

The gathering and hunting of the living resources of the sea, an activity of primitive societies on land and which have led to the near extinction of important fisheries in our oceans, will be replaced at sea by farming and herding.

High-tech barbed wire in the form of acoustic, thermal and other barrier techniques will emerge to control and manage the living resources of the sea. Oil and gas exploration and exploitation will continue moving into deeper and deeper water. Underwater parks, memorials and reserves will expand in size and scope until the TITANIC and other historic ships like her are easily visited by tourists using tele-operated robots in the comfort of their home on the information highway.

When ships and other pieces of human history fall into the deep sea, they enter a deep freeze, characterized by eternal darkness, freezing temperatures, and enormous pressures. Some estimate that there is more human history preserved in Davy Jones's locker than all the museums of the world combined.

The Black Sea and its anaerobic bottom water will give up some of the oldest and best preserved ships of ancient history, perhaps lost at a similar time when Jason and the Argonauts traversed these same waters in search of the Golden Fleece.

In recent years, we have discovered mineral deposits in the deep sea similar to those mined for centuries on islands like Cyprus. They contain high concentrations of copper, lead and sulfur, as well as silver and gold. And their formation continues today in the vast hydrothermal vent systems of the Mid-Ocean Ridge. These long linear mineral deposits may some day prove important resources for the next generation.

And the unique ecosystems, the chemosynthetic life forms that live around these hydrothermal vents, are processing toxic materials which are associated with that venting phenomenon. Perhaps some day we'll be able to bio-engineer those organisms to convert a portion of our waste products into less harmful, or even commercially valuable, byproducts.

Now whether this occurs during the next generation's time on earth, time will only tell. But I am convinced that much of what I have just outlined will come to pass.

The question is not will these things come to pass. The question is what nation will lead the way?

Had I been asked this question a mere five years ago, I would have said, without question, the United States of America will lead the way. But now I'm not so sure.

Just a few years ago, America had a tremendous lead, an incredible lead in ocean research and engineering that all nations of the world envied. But I'm not so sure that we can continue to lead the way.

We have become totally preoccupied with the present. We have forgotten that we are not about to enter the next decade. We're not about to enter the next century. We're about to enter the next millennium. And now is the time not to be short-sighted. Now is the time to form a vision of the future and to strive collectively towards that distant star.

America is a nation of pioneers with a long history of exploration and we are a critical crossroads that is not only important to our country, but to the human species.

There is no doubt in my mind that a better understanding of the oceans and the land surface beneath it is critical to our very survival.

The subsequent speakers will provide you with important insight into how our nation might best meet this challenge, and I support their recommendations, which I've read. They clearly represent the oceanographic community. You've got the firepower here today. And I understand their long-range objectives and how those objectives might be best achieved are good recommendations.

I've been following your efforts to fiscally put our house in order and I strongly endorse them. But I hope you get on with the task because it's critical that we move forward into the next millennium in a leadership position.

Thank you very much.

Mr. WELDON. Thank you for your excellent statement.

Dr. Albert?

[The prepared statement of Dr. Ballard follows:]

①

JOINT HEARING BEFORE

THE SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT OF THE HOUSE NATIONAL SECURITY COMMITTEE

THE SUBCOMMITTEE ON ENERGY AND ENVIRONMENT OF THE HOUSE COMMITTEE ON SCIENCE
AND

THE SUBCOMMITTEE ON FISHERIES, WILDLIFE, AND OCEANS OF THE HOUSE COMMITTEE ON RESOURCES

TEST~~IMONY GIVEN~~ BY

Dr. Robert D. Ballard
Senior Scientist, Woods Hole Oceanographic Institution
~~President,~~ Institute for Exploration
Chairman of the Board, JASON Foundation for Education
January 25, 1996

Dear Mr. Chairmen.

I want to thank you and the various members of the participating subcommittees for inviting me here day.

Modern research now suggests that all humans on the face of Earth come from a common ancestry that can be traced back to the plains of eastern Africa and that during the last 200,000 years, our ancestors journeyed forth from their birth place to populate the planet - first across the large Eurasian land mass and finally into the new world during the waning years of the Great Ice Age, just a few tens of thousands of years ago.

Many factors led to the global expansion of our forefathers. to search for food and shelter, a driving desire to escape oppression, a lust for economic gain or simply in pursuit of a better life for themselves and their loved ones. For whatever the reason, the fact remains our species now dominates the planet. We have all but conquered many of the forces that held us in check for oh so many millenniums.

Instead of being controlled by the forces of nature, we are now beginning to alter nature itself. Our activities have depleted the ozone layer, led to a build up of CO2 in the atmosphere, begun the destruction of the rain forests, and continue the premature extinction of many plants and animals we once lived in harmony with.

Some demographers now tell us that there are more people alive today than have ever died since our species began to populate the planet and that number will double again while we struggle through the next century. Despite the rhetoric about the need for population control, we continue to multiply, entering an era where reproduction is now endangering our existence instead of insuring our survival.

But I am not here today to tell you how to control the world's population. Even repressive measures in some countries have failed to accomplish that. I am simply an undersea explorer who has spent the last 30 years beneath the sea exploring its many wonders.

And I would like to take the next few minutes to tell you about what I have seen and try to guess what I think the future might hold for us given our continued growth and need for more space and resources.

Despite our globe trotting abilities, our species has not colonized any new land masses on the planet since the colonization of the new world which began in the 15th century. And let us not forget that the new world was already inhabited by our species long before Columbus first arrived in the Bahamas in 1492.

Today, the primary activities of our species is still confined to less than 20% of the planet, historically held at bay by an aquatic world that has resisted our colonizing ways.

Ironically, instead of turning to the sea for our future, we turned our eyes and our hearts to the heavens, convinced our future lay in space. Perhaps that day will come. But I am convinced not in time to save us given the path on which we now find ourselves.

I find it ironic that humans have lived in space for much longer periods of time than they have ever lived underwater. In fact, recent Congressional action is forcing our nation to abandon its only underwater research facility where scientists are able to live beneath the sea.

Isn't it interesting that Congress will fund studies aimed at living in space or on the surfaces of the moon and Mars but does not fund studies to see what technologies will be needed for us to live on the surface of the sea which surrounds us?

To me, the most important image to come out of the space program was when a astronaut on his way to the moon trained his cameras back on earth and captured an image of a very small greenish blue planet imbedded in a black velvet void of nothingness.

Ironically, we now have better topographic maps of Venus than Earth, we know more about the physiography of small volcanic cones on the far side of the moon than of similar features in our own exclusive economic zone off our shores. When President Reagan signed the bill creating the EEZ, the size of America doubled, yet most of this modern day Louisiana Purchase remains unexplored. And vast expanses of ocean floor in the southern hemisphere have never had an oceanographic research ship ever pass over them.

The largest single feature on the surface of the planet is the Mid-Ocean Ridge which runs around Earth like the seam of a baseball, covering almost one quarter of the planet's total surface area. Yet despite its tremendous size and the critical role it plays in the origin of Earth's outer skin, Neil Armstrong walked on the moon before the first human entered the largest feature on Earth when they dove to the Mid-Ocean Ridge's great rift valley in 1973.

Few people realize, that there are more active volcanoes underwater than on land, or know of the great plains that dwarf those in America, or of canyons far grander than the Grand Canyon, or that the mighty Rocky Mountains would fit into a small portion of the Mid-Ocean Ridge.

Given the emergence of advanced robotic technology, fiber-optics, micro-processors, virtual reality, autonomous vehicles, telecommunications, and many other new advances, the oceans will no longer be a barrier to human activity. The deep abyss will soon become our backyard and working at 20,000 feet which represents 98% of the world's oceans will become routine.

Given our exploding population and given the continued development of advanced technology, I truly believe the 21st century will usher in an explosion in human activity in the sea. I am convinced the next generation will explore more of Earth, that is the 71% that lies underwater, than all previous generations combined.

And just as Lewis and Clark's exploration of the Louisiana Purchase led to the settling of the west, the exploration of the sea will lead to its subsequent colonization. I have no doubt of that.

The gathering and hunting of the living resources of the sea, an activity characteristic of primitive societies on land and which has led to the near extinction of important fisheries in the oceans, will be replaced at sea by farming and herding.

High-tech barbed wire in the form of acoustic, thermal, or other barrier techniques will emerge to control and manage the seas living resources. The same debates over the destruction of the rain forest's bio-diversity on land in favor of ranching and farming will repeat itself as the great bio-diversity of the barrier reefs of the world are threatened by large scale farming of the sea.

Oil and gas exploration and exploitation will continue moving into deeper and deeper depths. We have already discovered and mapped oil and gas reserves down to depths of 12,000 feet which represents the average depth of the ocean and each year the oil industry brings production wells on line in waters deeper than the previous year.

Underwater parks, memorials and reserves will expand in size and scope until the TITANIC and other historic ships like her, are easily visited by tourists using tele-operated robots from the comfort of their home based telecommunications center.

When ships and other pieces of human history fall into the deep sea, they enter a deep freeze; characterized by eternal darkness, freezing temperatures, and enormous pressures. Some estimate that there is more human history preserved in Dave's Jones locker than all of the museums in the world combined.

During the six centuries that marked the rise and fall of the Roman Empire, Imperial Roman lost more than 10,000 commercial ships in the deep waters of the Tyrrhenian Sea, a small sea off the west coast of Italy. We are only now beginning to explore those waters.

The Black Sea and its anaerobic bottom water will get up some of the oldest and best preserved wooden ships in the world, perhaps lost at a similar time when

Jason and his argonauts traversed these same waters in search of the Golden Fleece.

On a far less glamorous note, some people are now suggesting that land fills will give way to the placement of waste in the vast abyssal deserts of the deep. Perhaps the storage of nuclear material will follow. Will this really happen? Do we know enough about the sea to take such a risk?

Present laws now forbid us from even the opportunity to find out if it is dangerous to place some of our waste in the deep sea. Dare we gamble with the lives of the next generation on a prayer and a dream by continuing to pollute our drinking water. Even when you include the heavy taxation on gasoline, high octane at the pump costs less per volume than Perrier which is certain to rise.

In recent years, we have discovered major mineral deposits in the deep sea similar to those mined for centuries on the island of Cyprus. They contain high concentrations of copper, lead, and sulfur as well as silver and gold. And their formation continues today in the vast hydrothermal vent systems of the Mid-Ocean Ridge. These long linear mineral deposits may someday prove to be important resources for the next generation.

Some of these magnificent vent areas with their exotic creatures will also become the Yellowstone Parks of the deep sea.

The unique chemosynthetic life forms that presently process the toxic materials associated with these vent communicates will hopefully be bio-engineered to convert a portion of our waste products into less harmful or even commercially valuable by-products.

These exotic creatures may also help us understand the early origins of life on our planet as well as the potential for life on other planets.

Whether this all occurs during the next generation's time on earth, time will only tell. But I am convinced that much of what I have just outlined will come to pass.

The question I can not answer is, what nation will lead the way. Had I been asked that question just five years ago, I would have said without pausing, the United States of America.

But now I don't know. Just a few years ago, America had a lead in ocean research and engineering that all nations of the world envied. But the gap is closing quickly. More importantly, we seem to have lost our way as well as our will to lead.

We have become totally preoccupied with the present. We have forgotten that we are about to enter, not the next decade, nor next century, but the next millennium.

Now is not the time to be shortsighted. Now is the time to form a vision of the future and to strive for that distant star on the horizon. America is a nation of pioneers with a long history of exploration.

We are at a critical crossroads in not only the history of this country but the history of the human race.

There is no doubt in my mind, that a better understanding of the oceans and the land surface beneath it, is critical to our very survival.

The previous speakers have provided you with important insight into how our nation might best meet this challenge and I support their recommendations. They clearly represent the oceanographic community and understand its long-range research objectives and how those objectives might best be achieved.

Getting our house in fiscal order is important but I urge all of you to get on with the task. Time is a wasting.

Thank You

(Appendix)

It is my understanding that the purpose of these hearings is to search for ways to make oceanographic research and development more efficient. In other words, are there ways in which the various and diverse elements of the oceanographic community can be encouraged to work together to increase their overall research and development objectives at a time of shrinking federal, state and local funding.

For the last 35 thirty years, I have participated in or led more than 110 oceanographic expeditions spanning the spectrum of purpose. As a Naval Officer I have conducted highly classified military missions. As a scientist with a Ph.D. in marine geology and geophysics, I have participated in numerous expeditions that have resulted in new discoveries about the natural history beneath the sea. As an explorer, I have found the TITANIC and even more important sites of true archaeological importance. As an educator and Chairman of the Jason Foundation for Education, I have sought to prepare the next generation of scientists, engineers, and naval officers for the challenges that face them in the next millennium, and as a private entrepreneur, I created private businesses that are now beginning to make the future I spoke of possible.

With this diverse background and interest, I have been able to forge alliances in research and development between the military, the academic world, and the private sector.

This year, for example, the JASON Foundation for Education will conduct its seventh educational field program off the coast of Florida. Here, research scientists; the U.S. Navy; NOAA, educational organizations including museums, research laboratories, Universities, schools systems; and private industry will work together for a common goal but with different ultimate objectives in mind.

Their common goal is to motivate the next generation of American youth to consider careers in science and technology - whether that is in the military, academia, or school systems or private industry. Their separate goals include the testing of new electronic systems aboard the submarine, specific research objectives, the education of our youth, and the development and testing of new telecommunications technologies.

The vast majority of the funds needed to carry out this program comes from the private sector; from the EDS Corporation, the Bechtel Group, Sprint, Eastman Kodak, and Sun Micro-systems. The U.S. Navy, through the Office of Naval Research, endorsed this research and educational program and provided unique military assets to make the program possible. NOAA has made its undersea habitat AQUARIUS available to this important program.

Last summer, a similar collaboration between the private sector, the U.S. Navy, and academic community took place in the Mediterranean Sea. Under the auspices of the Institute of Exploration in Mystic Connecticut, a comprehensive field program was conducted off the coast of Italy that provided new insight into the marine geology of the area as well as the discovery of ancient archaeological sites in 3,000 feet of water.

Once again, the majority of funds for this project came from the private sector but it was the cooperation of the U.S. Navy which extended their stay in the Mediterranean to make this project possible.

These are excellent examples of the goal this joint committee hearings have in mind. The question is, how was this possible, what mechanisms were in place, and can additional mechanisms be implemented to encourage even more joint cooperation between academia, the military, and the private sector.

In 1984, an important series of initiatives was created by then Secretary of the Navy, Dr. John F. Lehman. Complementing those initiatives was a major Oceanography Policy statement by then Chief of Naval Operations Admiral James Watkins who is your final speaker today. Those statements and initiatives in 1984 have proven critical over the intervening years to the objectives sought by today's hearings. At that point in time, the military and academic worlds were beginning to drift apart as a result of the Viet Nam War and the ending of the draft.

That process was somewhat reversed by the SECNAV Initiatives of 1984 in several important ways. First, it greatly enhanced the career path for young officers with advanced degrees in ocean science and engineering by changing the Navy's 1800 designator from Geophysics to Oceanography and by changing the flag billet of the Oceanographer of the Navy to an officer with an 1800 designator. Next it established a Master of Ocean Sciences Program for naval officers at the Massachusetts Institute for Technology and the Woods Hole Oceanographic Institution.

As a result, young officers were encouraged and rewarded for obtaining advanced ocean science and engineering degrees. Equally important, the officers that were accepted into this program were and continue to be some of the best and the brightest. Their presence on our academic campuses has changed the image and attitude academicians had of the "typical" naval officer, building bridges between the Navy and the oceanographic community.

Another SECNAV Initiative of 1984 was the establishment of the Secretary of Navy Chairs in Oceanography. These Chairs were awarded to leading oceanographers at the top oceanographic institutions in the United States and were mutually beneficial to both the military and the academic recipients. In short, it rewarded scientists interested in working with the military on shared research and development programs. This program was later replaced by a series of Fellowships and Graduate Research Assistantships awarded by the Office of Naval Research.

These initiatives also led to the construction of three important oceanographic research vessels that are owned by the Navy but operated by oceanographic institutions. The last of these three, the Woods Hole ARGO-25 ATLANTIS will be the support ship for the manned submersible ALVIN and the remotely operated vehicle system MEDEA/JASON which represent the premier academic deep submergence assets in the United States.

Finally, the SECNAV Initiatives of 1984 greatly expanded academic access to military deep submergence assets including the manned submersibles SEA CLIFF and TURTLE, the unmanned remotely operated vehicles SCORPIO and ATV, the only nuclear research submarine in the world, the NR-1, and their excellent support ships the LANEY CHOUEST and CAROLYN CHOUEST.

This initiative has been extremely successful and has resulted in several important science programs and, equally important, the transfer of important technologies from the private sector and academia to the military, enhancing their operational readiness. It has also provided scientists access to technology not previously available, helped augment military funding from private sources, and led to new applications of military technology for non-military purposes.

I strongly recommend that the subcommittees represented here today review the history of the 1984 SECNAV Initiatives as I believe they have proven to be extremely cost effective and have built important bridges between the military, the private sector, and academia. I also believe they need to be carefully reviewed to see what worked and what did not and how they might be given new life given the nature of reduced federal funding.

STATEMENT OF DR. BRUCE ALBERTS, PRESIDENT, NATIONAL ACADEMY OF SCIENCES

Dr. ALBERTS. Chairman Weldon, Chairman Saxton, Chairman Rohrabacher, and members, I'm pleased to be here today. I'm president of the National Academy of Sciences and in that position, I chair the National Research Council, which is the operating arm of the National Academies of Sciences and Engineering.

I'm of course here to testify about a matter of great importance and in doing so, I'll call on some previous studies, one just released this morning of the National Research Council dealing directly with U.S. oceanographic research.

There are two reports that you've been provided with of particular relevance and I'll mention them in my testimony. Of course, my written testimony is much more explicit than I can manage in oral statement.

The bottom line is that ocean science is a vitally important endeavor. In addition to maintaining the fisheries resources, our nation is faced with many other pressing marine issues, and they were mentioned by the Chairman this morning—economic competitiveness, national security, coastal hazards, environmental quality, biodiversity, and global change.

The question before us today is how can we ensure that the United States will continue to be a world leader or the world leader in ocean science and technology development in the years ahead?

My main point is this—the need for enhanced understanding of the ocean calls on us to strengthen the partnerships among federal agencies, academia, and the private sector. These issues have been directly covered in extensive studies which I can't do justice to today. I'll just mention some of them, very important recommendations, starting first with this report called "Oceanography—the Next Decade—Building New Partnerships."

In this 1992 report, the National Research Council made several recommendations regarding the future of ocean science that I believe should guide any discussion of enhancing our nation's ocean science effort, and I'll go through five of them quickly.

The first recommendation is that each agency with an ocean mission should establish permanent mechanisms for ensuring outside scientific advice, review and interaction.

The excellent relationships of the National Science Foundation and the Office of Naval Research with the academic community must be maintained and strengthened.

In addition, we need stronger partnerships between academic scientists in NOAA, NASA, the Department of Energy, the U.S. Geological Survey, and the Minerals Management Service. This would assure us of diversity and vitality in the national oceanographic effort.

The second recommendation is that because no single agency is able to oversee the total marine science agenda, a more effective means needs to be found for agencies to interact at the policy level and formulate action plans.

You'll hear more specific ideas later.

Such integrated planning must recognize the diverse roles that various individuals, agencies and research organizations play in our nation's ocean science effort.

The third recommendation is that each federal agency with a marine-related mission should find mechanisms to guarantee the continuing vitality of the underlying basic science on which their efforts depend.

Maintaining diversity and balance in the funding of research and development is of paramount importance to maintaining our nation's leadership position in science and technology all across the board.

The fourth recommendation is that federal and academic researchers should improve the cooperative use of facilities and the conduct of joint research.

And the fifth recommendation is that the present system for data management and exchange within and among the various elements of the marine science community needs to be modernized and improved.

My final point is that academia and federal agencies should also make greater efforts to develop stronger relationships with private-sector scientists.

This issue is stated and explained in much more detail in the report that was just released this morning for the National Research Council, entitled, "Expanding the Uses of Naval Ocean Science and Technology."

Let me quote:

"Ocean science research and technology development that lead to reduced environmental impact of offshore activities that increased efficiency in the work place, and improved data collection, assimilation and dissemination, would be of value to a wide range of non-military marine users."

Conversely, the practical experience and technical expertise of the private-sector scientists, engineers and offshore operators could prove to be a valuable resource to both academic and government personnel.

So, to summarize, we must maintain our commitment to ensuring that our limited resources are made available to the best scientists and applied towards the most critical problems. This means that we must do a better job of building broader and more interactive relationships.

Increased cooperation and planning and use of physical resources, such as ships, satellites, and submersibles, would result in increased efficiency and better science. And enhanced communication between the users and producers of basic and applied research will strengthen the system of scientific endeavor that has made the United States the world leader in ocean science.

Mr. Chairman, I thank all of you for this opportunity to testify and the National Research Council is pleased to be of service to the nation.

[The prepared statement of Dr. Alberts follows:]

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Testimony of

Dr. Bruce Alberts, President of the National Academy of Sciences

before the

House Committee on National Security, Subcommittee on Military Research and Development - Rep. Curt Weldon (PA), Chairman,

the

House Committee on Resources, Subcommittee on Fisheries, Wildlife and Oceans - Rep. Jim Saxton (NJ), Chairman,

and the

House Committee on Science, Subcommittee on Energy and Environment - Rep. Dana Rohrabacher (CA), Chairman

25 January 1996

Chairman Weldon, Chairman Saxton, Chairman Rohrabacher, and Members of the Subcommittees: I am Bruce Alberts, president of the National Academy of Sciences and chairman of the National Research Council (NRC), the operating arm of the National Academies of Sciences and Engineering, and the Institute of Medicine. I am pleased to testify before you today on a topic of great importance -- the health and future of this nation's scientific investigation of the world's oceans. Over the past several years, boards and committees of the NRC have studied the nature and health of various aspects of U.S. research into the physical, chemical, biological, and geological processes that characterize the fluid that covers two-thirds of our planet's surface. These studies have highlighted the critical role that the ocean plays in global-scale processes as well as the importance that ocean resources can have for the economies of local communities, states, and regions. In addition to highlighting the role of science in improving our understanding of the relationship between the ocean and human activities, NRC studies have addressed the essential partnerships among government, academia, and the private sector that make effective research in ocean science possible.

I will focus my remarks on four major issues relavent to our national oceanographic capabilities: (1) the importance of ocean science; (2) essential elements of an ongoing, healthy national ocean science effort; (3) present U.S. capabilities for conducting ocean science; and (4) the outlook for ocean science. In addressing these topics, I will draw largely from reports of the Ocean Studies Board (OSB), the unit within the NRC responsible for oceanographic research and marine resources. Copies of these reports have been provided for use by you and your staff.

In a 1992 report, *Oceanography in the Next Decade: Building New Partnerships*, the NRC made several recommendations regarding the future of ocean science in this country and the nature of the partnerships needed for its continued health. These recommendations are particularly relevant to today's hearing; I include them here to provide context for my testimony:

- Each agency with an ocean mission and without strong links to the nongovernment community should establish permanent mechanisms for ensuring outside scientific advice, review, and interaction.

- Because no single agency is charged with and able to oversee the total national marine science agenda, an effective means needs to be found for agencies to interact at the policy level and formulate action plans.
- Federal agencies with marine-related missions should develop mechanisms to guarantee the continuing vitality of the underlying basic science on which they depend.
- Federal and academic researchers should improve the sharing of data, the cooperative use of facilities, and the conduct of joint research.
- The present system for data management and exchange within and among the various elements of the marine science community should be modernized to reflect the existence of distributed computing systems, national and international data networks, improved satellite data links, and on-line distribution of oceanographic data.

The Importance of Ocean Science

I would like to preface my comments by sharing with you the words of my predecessor, Dr. Frank Press, in his introduction to *Oceanography in the Next Decade: Building New Partnerships*:

> The ocean has always had a profound influence on human life. It has been an important source of food and means of commerce. However, it has

> also been a threat to human life as a focus for war and through its encroachment onto land. In recent decades, the United States has been the world leader in ocean research, both in basic studies and research on the ocean's particular influence on human activities. This pioneering work has largely been the result of remarkably successful partnerships between federal agencies and research in universities, in which federal agencies support the research of academic scientists and academic scientists provide advice on internal and external research by a variety of mechanisms.
>
> However, the world in which these partnerships were created and sustained is changing rapidly. Concerns about the ocean as a medium for warfare and as a threat to our national security are decreasing while environmental problems of the coastal zone and understanding how the ocean controls climate are of increasing importance.

I echo these sentiments by strongly emphasizing the need for a sustained effort to understand the role of the ocean in human activities, recognizing the continually changing challenges facing society and the ocean science community. For example, U.S. and world fisheries are an increasing concern; since 1988 the total world harvest of marine fish has plateaued and the stocks of many commercial species in U.S. waters are fully utilized or overutilized. Continued efforts on the part of some fishing countries to maintain or even increase their total catch has exerted tremendous pressure on virtually all commercial fish stocks, resulting in conflict, at times violent, over this limited resource. This plateau in one of the world's most important food supplies, viewed in the context of an increasing world population, can only serve to exacerbate tensions in the post-Cold War era. This challenge is so important that the National Academy of Sciences has awarded funds to the Ocean Studies Board to conduct a study on ecosystem management for sustainable marine fisheries.

In addition to maintaining fisheries resources, our nation is faced with other pressing marine problems whose timely solution will require increased cooperation between the federal government, academia, and the private sector, including:

- Economic Competitiveness, Basic and applied research in the marine sciences and engineering is necessary to achieve and maintain a competitive position in a host of fields, including marine biotechnology, aquaculture, hydrocarbon and mineral exploration and production, maritime transportation, fisheries, treatment and disposal of waste, and freshwater extraction.
- National Security, Experience gained from naval activities in the Persian Gulf during operations Desert Shield and Desert Storm highlights the need for better information related to oceanic and coastal processes and to maritime operations and transportation.
- Coastal Hazards, The Atlantic Ocean hurricane season of 1995 was one of the most severe in this century, occurring at a time when the memories of hurricanes Hugo and Andrew were still fresh in the minds of many citizens of the southeastern United States. Land loss due to coastal erosion threatens significant portions of U.S. coasts, destroying wetlands and the beach resources of many coastal states.

- Environmental Quality, Environmental threats in the form of contamination, such as the dumping of radioactive waste or the spilling of petroleum by the former Soviet Union (as testified to in joint hearing of the Military Research and Development Subcommittee of the House National Security Committee and the Fisheries, Wildlife and Oceans Subcommittee of the House Resources Committee on December 5, 1995), imperil the open ocean and the living resources it shelters.
- Biodiversity, The genetic diversity of life on this planet is not only critical to maintaining the health of critical ecosystems, but also offers the promise of significant new discoveries in medicine and other fields. Recent research suggests that the ocean represents the largest reservoir of biological species and that we have only just begun to quantify their importance in medicine.
- Global Change, Regional events such as El Niño and changes in ocean circulation influence climate on both seasonal and longer time scales. Research efforts have led to better predictions of year-to-year variation, but considerable work remains to make these forecasts operational.

Effective policy decisions concerning these and other marine issues require a strong foundation of reliable scientific information based on a comprehensive understanding of the world's ocean. The need for enhanced understanding of the ocean calls on us to reexamine and strengthen the partnerships among federal agencies, academia, and the private sector. These partnerships have formed the leadership role the United States has enjoyed in ocean science.

Essential Elements of a Ongoing, Healthy National Ocean Science Effort

Basic oceanographic research has been funded largely by the Office of Naval Research (ONR) and the National Science Foundation (NSF), agencies whose missions include maintaining the long-term excellence and vitality of ocean science in this country. Fundamental investigations sponsored by NSF and ONR are complemented by research supported by a number of agencies that require more specific information related to resource management and regulatory oversight. The more focused, "mission-oriented" research is an essential component of this nation's ocean science effort because it sustains a reliable base of critical, long-term observations of oceanic conditions and processes (such as that provided by the weather and climate research programs of the National Oceanic and Atmospheric Administration [NOAA]). Mission-related research also provides valuable insights into oceanic processes critical to the health and vitality of marine ecosystems and resources. A strong national effort in ocean science with an appropriate balance of both types of research is the key to long-term success. As stated in the recent NRC report *Allocating Federal Funds for Science and Technology*:

> The growth of federal science and technology from multiple roots in mission agencies has resulted in a pluralistic research and development system. Although some may see needless overlap in such a system, in reality pluralism is a great source of strength, an advantage over the ways research and

> development are organized in many other countries. The diversity of performers fosters creativity and innovation. . . . At the same time, diverse funding alternatives give original ideas a better chance to find support than would a more centralized system.

Research to address today's concerns, along with a long-term commitment to fundamental research, provides a hedge against unforeseen challenges by advancing the human understanding of the planet on which we live.

Present U.S. Capabilities for Conducting Ocean Science

The capacity of any nation to conduct basic ocean research is a direct function of resources available, including (1) human, (2) physical, and (3) fiscal resources. Human resources include well-trained scientists, engineers, and technicians. Researchers from a broad range of ocean science subdisciplines are needed to solve the complex, ocean-related resource and environmental problems that face our nation. Physical resources are needed in the form of adequate facilities, including laboratories, ships, submersibles, computing resources, and satellites. As ocean science problems become more complex, requiring long-term and complex sampling strategies and research efforts, the stability of the fiscal resources supporting those scientific endeavors becomes a greater factor in their success.

The federal government has been the major supporter of ocean science in the United States since the end of World War II. Advances in ocean science have been accomplished largely by federal agencies joining with individual scientists in academia to form productive partnerships. These partnerships have advanced ocean science, providing many benefits to society. I would like to briefly review the human, physical, and fiscal resources presently available in the United States and how they affect our capability to conduct ocean science.

Human

Public and private institutions have developed an excellent graduate education system in the United States, yielding individuals employed in government, academia, and the private sector. According to a survey conducted by the OSB, the number of Ph.D.-level academic scientists in the United States increased about 70 percent from 1980 to 1990. This period of growth has ended, because the number of Ph.D.-level academic scientists has remained relatively constant during the past 4 years. Moreover, acceptance of incoming students in oceanographic graduate programs decreased about 30 percent from 1992 to 1995. However, the United States still possesses a significant human resource to conduct ocean science and a tradition of excellence in ocean science education.

Excellence in ocean science education can benefit general science education as a whole in the United States, because ocean science is a topic that excites students of all ages. For example, ocean science is used in K-12 education as a vehicle to develop interest in science, ultimately helping increase our nation's scientific literacy. Admiral Watkins, a leader of the Ocean Planet exhibit scheduled to tour America as part of the 150th Anniversary celebration of the founding of the Smithsonian Institution, can testify to the potential value of public interest in the ocean as a stimulus to increase scientific literacy.

Physical

The United States possesses an oceanographic fleet composed of ships owned and operated primarily by academic institutions, the Navy, the National Oceanic and Atmospheric Administration (NOAA), and private corporations. However, aging of some key components of the fleet, coupled with a strong demand for ship time, dictates that greater coordination between academia and the federal sector will be necessary to ensure that the needs of ocean scientists and the nation are met.

The success of completed or ongoing satellite missions, such as TOPEX-POSEIDON and GEOSAT, demonstrates that spaced-based missions need to be an integral and increasingly significant component of our nation's ocean science effort. In the case of satellite resources, an important component of many modern oceanographic projects, the capabilities of U.S. platforms has declined in recent years, and many planned ocean missions have been delayed or cancelled.

Fiscal

Oceanography in the Next Decade: Building New Partnerships demonstrated that from 1982 to 1992 federal funding for ocean science remained essentially constant (when adjusted for inflation). Since 1992, the federal agencies that fund ocean science (apart from NSF) have experienced a downward trend in funding. Many mission agencies that support external scientific research have been targeted for elimination. A stable fiscal climate is an important component of productive and efficient partnerships. This is particularly significant, because as the physical resources needed to conduct large-scale, interdisciplinary research become more sophisticated, their costs rise faster than the rate of inflation.

Overall

A competitive, peer review approach to selecting and funding research projects is the foundation of this nation's leadership in science and technology. As stated in *Allocating Federal Funds for Science and Technology*, "The challenge in the current period is to retain diversity and balance while cutting back is some areas to free resources for better or more important activities." In short, we must maintain our commitment to ensuring that resources are available to the best scientists and applied toward the most critical problems. A truly efficient and effective ocean science effort within the United States must, however, encourage partnerships not only among federal agencies and academia. but with the private sector as well.

Private sector involvement is important to achieving the maximum benefit from the resources available. As discussed in the recent NRC report *Expanding the Uses of Naval Ocean Science and Technology*, the private and academic sectors could benefit from the marine research and development conducted routinely at government facilities and institutions sponsored by ONR. Cooperative research between ONR and private industry could range from high-profile activities, such as the high-resolution meteorological models developed in 1995 to aid in the U.S. defense of the America's Cup, to potential breakthroughs in extremely practical problems, such as marine corrosion and biofouling (familar to any marine boat owner, the Navy alone spends an estimated $3 billion a year combating this age-old problem). Other agencies that support ocean scientists in agency laboratories (e.g., Department of Energy, U.S. Geological Survey, NOAA) have the potential to transfer useful science and technology to the nongovernmental sector. Research conducted by academic scientists and funded by federal agencies is commonly published in the scientific literature, but the implications of this research may not be obvious to potential governmental or commercial users. Strategic partnering and development of mechanisms for transfer of research results and technology among the private sector, academia, and federal agencies would strengthen U.S. capabilities in basic and applied ocean science. Such mechanisms would also promote U.S. economic competitiveness and our ability to respond to national security and environmental challenges.

The United States possesses significant capabilities for conducting ocean science. Faced with limited resources, federal agencies, academia, and the private sector must pursue a greater level of cooperation and efficiency. Only with coordinated and strong partnerships can we ensure that the United States will continue to be a world leader in ocean science and technology development.

The Outlook for Ocean Science

Maintaining diversity and balance in the funding of research and development is of paramount importance to maintaining our nation's leadership role in science and technology. As stated in the recommendations of *Allocating Federal Funds for Science and Technology*, ". . . integrating the needs of a pluralistic research and development system requires a comprehensive overview and careful planning." Such an integrated plan must recognize the diverse roles various individuals, agencies, and research organizations play in our nation's ocean science effort. Federal agency responsibilities range from the active promotion of the health of basic science in NSF and ONR to the highly specific and focused research of the mission agencies. To continue progress in our basic understanding of the ocean, the excellent relationships of NSF and ONR with the academic community must be maintained and strengthened. Other federal agencies that are involved in marine science and policy vary widely in how they make use of the research potential represented by the academic community. Stronger partnerships between academic and private-sector scientists and NOAA, the National Aeronautics and Space Administration, the Department of Energy, the U.S. Geological Survey, and the Minerals Management Service, would add diversity and vitality to the national oceanographic effort.

Again, academia and federal agencies should make greater efforts to develop stronger relationships with private-sector scientists. As stated in *Expanding the Uses of Naval Ocean Science and Technology*, "Ocean science research and technology development that lead to reduced environmental impact of offshore activities, increased efficiency in the workplace, and improved data collection, assimilation, and dissemination would be of value to a wide range of nonmilitary marine users." Conversely, the practical experience and technical expertise of private sector scientists, engineers, and offshore operators could prove to be a valuable resource to academic and government personnel.

A reexamination of the present partnerships between federal agencies, academia, and the private sector can have a beneficial effect if careful attention is given to preserving those aspects of existing partnerships that work well while building broader, interactive relationships. In particular, increased cooperation in planning and use of physical resources (e.g., ships, satellites, and submersibles) could result in increased efficiency and better platforms for ocean science. Enhanced communication between the users and producers of basic and applied research can only strengthen the system of scientific endeavor that has earned and maintained the United States a place as the world leader in ocean science.

Thank you Chairman Weldon, Chairman Saxton, Chairman Rohrabacher, and Members of the Subcommittees for your interest in the NRC's recommendations regarding the future of oceanographic research in the United States.

Mr. WELDON. Thank you, Dr. Alberts.

Dr. Lane?

STATEMENT OF DR. NEAL LANE, DIRECTOR, NATIONAL SCIENCE FOUNDATION

Dr. LANE. Thank you.

Chairman Weldon, Chairman Rohrabacher, Chairman Saxton, and members of the Committee, I very much appreciate the opportunity to testify on national oceanographic research capabilities.

I'd like to give a brief overview of ocean science research at the National Science Foundation and follow with two examples of specific types of projects we support, before I address some of the broader national oceanographic policy issues.

At NSF, ocean sciences research and education is largely supported through our Geosciences Directorate, which also supports research in related fields of Earth Sciences and Atmospheric Sciences.

In 1995, the Ocean Sciences subactivity was funded at the level of $193 million, which represents just over eight percent of the NSF's total research budget.

Among other things, these funds provided support for more than 3000 scientists and graduate students, 27 research vessels, and over 3000 operating days at sea.

An additional $29 million for ocean sciences research comes from our Office of Polar Programs, which supports ocean science research in the Arctic and Antarctic regions.

So, in total, NSF provides support for these fields at a level of well over ten percent of our entire research budget.

Conducting state-of-the-art research on the oceans is a daunting challenge, not only because of the sheer size and the physical complexity of two-thirds of the earth's surface that comprise the oceans, but because the research requires ocean-going platforms equipped with scientific instruments that are capable of operating in some of the most severe environmental conditions imaginable.

The potential pay-offs for this research, both in terms of advancing scientific understanding and in potential economic benefits, are enormous, but let me just give you two examples, please.

Ocean fishermen and the coastal communities that are economically dependent on their success are subject to huge fluctuations in commercial fishstocks. Some yield record catches, but these are often followed by periods of virtual absence of certain species of commercial fish. A common sense interpretation of these cycles blames the scarcity of fish in the lean years on overfishing during the boom part of the cycle.

Sedimentary records of the ocean floor, however, provide data going back hundreds, even thousands, of years that show boom or bust cycles in fish populations. This strongly suggests that natural environmental variability is an important factor in fish populations. This cyclic variability can vary from season to season, or it may vary across decades or more.

The reasons for the cyclic variability are complex, but are probably tied to the reproduction strategies of fish. Most fish produce thousands or even millions of offspring per adult in each breeding cycle. The vast majority of these offspring perish due to predation, harsh environmental conditions, and starvation. If only one percent of a million eggs spawned by a single female survive to adulthood, the adult population would increase 5000-fold.

Understanding and predicting the natural fisheries fluctuation will require incorporating biological data into the development of physical models of ocean activity. This in turn will require tapping into the growing capability of supercomputers and supercomputer software to handle massive amounts of data, improved technological innovation in environmental sampling, and the training of graduate students in the use of emerging research techniques.

Understanding the cycles of commercial fish populations is in one sense only a by/product of the basic research and that National Science Foundation supports. But as the federal agency supports research and education in each scientific discipline, NSF has an additional responsibility of connecting that research to problem areas of national interest.

That requires strong partnerships, not only among agencies and with universities, but with the industries that can take the knowledge and the technologies that come out of research and apply them to the needs of the people.

Let me offer one other example.

One of the most spectacular results of the slow drift of the continents is found along the mid-ocean ridge system that Dr. Ballard mentioned earlier. Heat that is transferred to the ocean from the hot, fractured volcanic rock along the mid-ocean ridge has an important impact on the chemistry of the oceans and may have significant effects on their biological productivity as well.

About 20 years ago, researchers aboard deep-diving submersibles like ALVIN made a totally unexpected discovery of a broad range of living plants and marine animals among these hydrothermal vents. While this has been tremendously exciting as a scientific discovery, it has had important economic implications as well.

The unique, heat-resistant enzymes isolated from bacteria found in hot water vents have provided products used in the multi-million dollar biotechnology industry and in basic molecular biological research.

In 1993, the ALVIN submersible found evidence of a large community of bacteria that live in porous rocks well beneath the seafloor. Some researchers estimate that the biomass of this subseafloor biosphere is comparable to the mass of all living things on the surface of the earth.

Discoveries of deep seabed and sub-seafloor life forms have opened up entirely new avenues of research and opportunities for understanding the complex interactions between living organisms and their environment.

These are only a few of the literally scores of topics included in our ocean science research support, each with an equally interesting story to tell. These success stories, however, are not the result of heroic efforts of NSF supporting research in isolation. Instead, they reflect collaborative programs that involve academic researchers, agency scientists, oceanographers, and resource managers in other federal agencies and in international efforts.

In our research activities that are relevant to fisheries, NSF has worked to develop partnerships between the best academic researchers and their counterparts in ocean resources sciences at NOAA. Our collaborative efforts with NOAA are essential to the conduct of good science, and internationally, this partnership has expanded to include informal research partnerships with research agencies in scores of foreign countries.

NSF has also been a major proponent of an international program under the International Council for the Exploration of the Sea.

Research on the multiple factors that affect commercial fish populations is exemplified in our Global Ocean Ecosystems Dynamics Program, called GLOBEC, which we initiated three years ago to understand the collapse of the cod and haddock fisheries in the George's Bank region off the coast of New England and up the coast of Newfoundland. Representatives of the commercial fisheries industry have participated in this program.

On the U.S. side, extensive effective partnerships have been developed among NSF, NOAA, NASA, DOE and ONR to provide both needed data and the tools needed to interpret this data.

The NSF and our federal partners, however, cannot support all the research and the ship operations, the data analysis, and the modeling required on the global scale.

On the international scene, we're working with over 30 countries to meet the scientific program requirements. These global programs require deployment of the research vessels to all the major oceans of the world.

The development and support of the U.S. academic research fleet represents a particularly effective and long-standing partnership between NSF and ONR that has developed over the past 25 years. This particular partnership has resulted in a world-class fleet of ocean research vessels. It's the result of mutual trust and a shared understanding of the fundamental research that is important in ocean sciences for national security, but also for economic vitality and environmental monitoring.

Ocean science research can help us understand the role of the oceans in global phenomenon, including near-term weather prediction, long-term climate change, coastal ecology, and the impact of pollution on the environment. It can also provide an understanding of the ocean as a source of food, of minerals, and of energy.

The ocean research supported by NSF is an example of the close connection between fundamental research on topics of pure scientific interest and the value that that research has for real-world concerns.

The National Science Foundation has recently completed a strategic planning process that stresses the need to promote not only the discovery of new knowledge, but its employment in service to society.

In the past, many in the research community felt that their mission was to use technology to probe the mysteries of nature, and that certainly is a very important mission.

But our goal at NSF is to expand this vision of the researcher's responsibility so that research can be more clearly related to national interests.

All federal agencies are facing budgetary pressures as we struggle to balance the budget. We cannot take for granted that research budgets will grow in the future. Indeed, we must be prepared for future budgets that may provide little or no real growth. This makes it imperative that we look for ways to do what we can do even better and that includes developing new ways of coordinating research across agencies and leveraging resources both inside the government and in the private sector.

NSF's long history of collaboration with other agencies that support research and education in ocean sciences makes me optimistic that we can continue to build on this base in the future. Continued success will depend on our ability to demonstrate to the public how even research in this most fundamental scientific area has implications for improving the quality of our lives.

The burden of clearly articulating the benefits of federally funded scientific and engineering research and education falls squarely on the shoulders of the research community. These benefits include not only pushing back the frontiers of scientific knowledge, but also educating the next generation of researchers and the scientifically literate citizen who knows how to weigh the potential future value of new discoveries against the cost of the current investments.

So as you can see, Mr. Chairman, the success of ocean research has been based on strong partnerships in the past. Recognizing this and in the interest of implementing many of the recommendations coming from the oceanographic community, the NSF initiated discussions two years ago on how to improve the field through new partnerships.

We have benefited from sharing ideas with the community, with Admiral Watkins, and we look forward to the testimony coming forward in the rest of this hearing.

In closing, I want to be on record that NSF is eager to work with the relevant agencies to explore appropriate ways to improve the quality and the coordination of research in the ocean sciences.

I would be happy to respond to any questions you might have. I would like to apologize in advance, Mr. Chairman. I may have to leave before the end of the question session, with your permission.

I brought with me today Dr. Robert Corell, who is assistant director of our Geosciences Directorate, who can certainly answer any questions you might have about NSF's role.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Lane follows:]

3

TESTIMONY OF
DR. NEAL LANE
DIRECTOR, NATIONAL SCIENCE FOUNDATION

BEFORE THE
HOUSE COMMITTEE ON NATIONAL SECURITY
SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT

HOUSE COMMITTEE ON RESOURCES
SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS

HOUSE COMMITTEE ON SCIENCE
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT

January 25, 1996

Chairman Weldon, Chairman Rohrabacher, Chairman Saxton, and members of the committees, I very much appreciate the opportunity to testify on national oceanographic research capabilities.

I would like to begin with an overview of ocean sciences research at the National Science Foundation, and follow with some examples the types of projects we support before I address some of the broader national oceanographic policy issues.

At NSF, ocean sciences research and education is largely supported through our Geosciences Directorate, which also supports research in the related fields of Earth Sciences and Atmospheric Sciences. In 1995, the Ocean Sciences subactivity was funded at $193 million, which represents just over 8 percent of the agency's total research budget. Among other things, these funds provided support for more than 3,000 scientists and graduate students, 27 research vessels, and over three thousand operating days at sea. An additional $29 million for ocean sciences research comes from our Office of Polar Programs which supports ocean science research in the arctic and Antarctic regions.

Conducting state-of-the-art research on the oceans is a daunting challenge, not only because of the sheer size and physical complexity of the two-thirds of the earth's surface that comprise the oceans, but because the research requires ocean-going platforms equipped with scientific instruments that are capable of operating in some of the most severe environmental conditions imaginable. The potential pay-offs from this research, both in terms of advancing scientific understanding and in potential economic benefits are enormous. Let me give you a few examples.

Ocean fishermen -- and the coastal communities that are economically dependent on their success -- are subject to huge fluctuations in commercial fish stocks. Some years yield record catches, but these are often followed by periods of virtual absence of certain species of commercial fish. A common sense interpretation of these cycles blames the scarcity of fish in the lean years on overfishing during the boom part of the cycle.

Sedimentary records from the ocean floor, however, provide data going back hundreds, even thousands of years that show "boom-and-bust" cycles in fish populations. This strongly suggests that natural environmental variability is an important factor in fish populations. This cyclic variability can vary from season to season, or it may vary across decades or more.

The reasons for the cyclic variability are complex, but are probably tied to the reproduction strategies of fish. Most fish produce thousands or even millions of offspring per adult in each breeding cycle. The vast majority of these offspring perish due to predation, harsh environmental conditions, and starvation. If only one percent of a million eggs spawned by a single female survive to adulthood, the adult population would increase five-thousand fold!

Understanding and predicting the natural fisheries fluctuations will require incorporating biological data into the developing physical models of ocean activity. This, in turn will require tapping into the growing capability of supercomputers to handle massive amounts of data, improved technological innovation in environmental sampling, and the training of graduate students in the use of emerging research techniques. Understanding the cycles of commercial fish populations is in one sense only a byproduct of the basic research that NSF supports. But as the Federal agency supports research and education in each scientific discipline, NSF has an additional responsibility of connecting research to problem areas of national interest.

Let me offer another example. One of the most spectacular results of the slow drift of the continents is found along the mid-ocean ridge system. Heat that is transferred to the ocean from hot, fractured volcanic rock along the mid-ocean ridge has an important impact on the chemistry of the oceans and may have significant effects on their biological productivity as well.

About 20 years ago researchers aboard deep-diving submersibles like ALVIN made a totally unexpected discovery of a broad range of living plants and marine animals along these hydrothermal vents. While this has been a tremendously exciting scientific discovery, it has had important economic implications as well.

The unique, heat-resistant enzymes isolated from bacteria found in hot water vents have provided products used in the multimillion dollar biotechnology industry and in basic molecular biological research.

In 1993, the ALVIN submersible found evidence of a large community of bacteria that live in porous rocks well beneath the seafloor. Some researchers estimate that the biomass of this sub-seafloor biosphere is comparable to the mass of all living things on the earth's surface. Discoveries of deep seabed and sub-seafloor life forms have opened up entire new avenues of research and opportunities for understanding the complex interactions between living organisms and their environment.

NSF Role in Collaborative Efforts

These are only a few of the literally scores of topics included in our ocean science research support, each with an equally interesting story to tell. These success stories however are not the result of heroic efforts of NSF supporting research in isolation. Instead, they reflect collaborative programs that involve academic researchers, agency scientists, oceanographers, and resource managers in other federal agencies and in international efforts. In our research activities that are relevant to fisheries, NSF has worked to develop partnerships between the best academic researchers and their counterparts in ocean resource sciences at NOAA. Our collaborative efforts with NOAA are essential to the conduct of good science. Internationally, this partnership has expanded to include informal research partnerships with research agencies in scores of foreign countries. NSF has also been a major proponent of an international program under the International Council for the Exploration of the Sea.

Research on the multiple factors that affect commercial fish populations is exemplified in our Global Ocean Ecosystems Dynamics Program (GLOBEC) which we initiated three years ago to understand the collapse of the cod and haddock fisheries in the George's Bank region off the coast of New England and up the coast as far as Newfoundland. Representatives of the commercial fisheries industry have participated in this program.

On the U.S. side, extensive effective partnerships have been developed among NSF, NOAA, NASA, DOE, and ONR to provide both needed data and the tools needed to interpret this data. The NSF and our federal partners, however, cannot support all the research, ship operations, data analysis, and modeling required on the global scale. On the international scene, we are working with over 30 countries to meet the scientific program requirements. These global programs require deployment of research vessels to all the major oceans of the world.

The development and support of the US academic research fleet represents a particularly effective and long-standing partnership between NSF and ONR that has developed over the past 25 years. This particular partnership has resulted in a world-class fleet of ocean research vessels. It is the result of mutual trust and a shared understanding that fundamental research in ocean sciences is equally important for national security, economic vitality, and environmental monitoring.

Future Policy Implications

Ocean science research can help us understand the role of the oceans in global phenomenon including near term weather prediction, long term climate change, coastal ecology, and the impact of pollution on the environment. It can also provide an understanding of the ocean as a source of food, minerals, and energy.

The Ocean research supported by NSF is an example of the close connection between fundamental research on topics of pure scientific interest and the value that that research has for real world concerns. The National Science Foundation has recently completed a strategic planning process that stresses the need to promote not only the discovery of new knowledge, but its employment in service to society. In the past, many in the research community felt that their primary mission was to use technology to probe the mysteries of nature. Our goal at NSF is to expand this vision of the researcher's responsibility so that research can be more clearly related to national interests.

All Federal agencies are facing budgetary pressures as we struggle to balance the budget. We cannot take for granted that research budgets will grow in the future; indeed we must be prepared for future budgets that may provide little or no real growth. This makes it imperative that we look for ways to do what we do even better and that includes developing new ways of coordinating research across agencies and leveraging resources both inside the government and in the private sector.

NSF's long history of collaboration with other agencies that support research and education in the ocean sciences makes me optimistic that we can continue to build on this base in the future. Continued success will depend on our ability to demonstrate to the public how even research into the most fundamental scientific questions has implications for improving the quality of our lives. The burden of clearly articulating the benefits of Federally funded scientific and engineering research and education falls squarely on the shoulders of the research community. These benefits include not only pushing back the frontiers of scientific knowledge but also educating the next generation of researchers and scientifically literate citizens who know how to weigh the potential future value of new discoveries against the cost of current investments.

In closing, I want to be on record that NSF is eager to work with relevant agencies to explore appropriate ways to improve the quality and the coordination of research in the ocean sciences.

I would be happy to respond to any questions that you might have.

Mr. WELDON. Thank you, Dr. Lane, for your testimony.

Dr. Jim Baker?

STATEMENT OF DR. D. JAMES BAKER, UNDER SECRETARY FOR OCEANS AND ATMOSPHERE, AND ADMINISTRATOR, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Dr. BAKER. Thank you, Mr. Chairman.

I have to say we're very glad to see you back in the chair as a very strong supporter of oceans issues across the government.

So congratulations on your successful recovery.

And also to Chairman Rohrabacher, who shares a common Long Beach heritage with me. We've had some interesting discussions back and forth and his advice has been very helpful to us in NOAA as we adjust our priorities.

And to Chairman Saxton, who also has been a long-term supporter of ocean issues, particularly ocean and coastal issues. It's been great to work with you and we're looking forward to trying to develop these issues further.

And I want to say to Congressman Kennedy that I appreciate the opportunity to work with you on the Rhode Island oil spill. As you know, I think we're putting together the fastest federal response to get funding out to those people who are affected as fast as we can.

I think it shows what we can do with support of the congressional delegation and all the science agencies. Coast Guard is the lead and NOAA has been working very closely with the Coast Guard there.

Thank you for the opportunity to testify about the cooperative role that's played by NOAA in the nation's oceans programs.

We recently celebrated our 25th year of service to the nation as a focus for management and conservation of ocean resources for providing ocean services and civilian ocean research.

And as you know, we cooperate with other federal and state agencies, with the academic community, with private industry, with nongovernmental organizations, in order to carry out those responsibilities.

NOAA was created as a result of the Stratton Commission review that envisioned that NOAA would provide vital services to industry and the public according to its core mission to describe and monitor and predict changes in the earth's environment. And that it would promote conservation and wise management of the nation's marine and coastal resource, so that we could enhance sustainable economic opportunities.

The Stratton Commission characterized the earth as a dynamic system in which the ocean and atmosphere are linked.

In carrying out our respective missions over the last quarter century, NOAA and its partners have learned the truth of that linkage and our knowledge continues to grow.

As a result, many practical benefits have been achieved.

But the public has yet to reap the full benefit of the commission's vision. During the last 25 years, the scale and importance of oceans issues have increased dramatically. We've learned a lot about how the system works and where the pressures on the system are.

At the same time, we face decreasing financial resources with which to work.

The oceans are important to the nation as a driver of weather and climate, as a marine highway, to link the United States with the global economy. About 99 percent of all the goods that come into the United States come in ship.

As a vital source of food, oil and gas.

As a source of new medicines and other resources for sustainable economic development.

As a source of recreational opportunities and a theater for defense.

NOAA works actively with the Navy, the Departments of State and Interior, the Coast Guard, the Geological Survey, the Defense Mapping Agency, NASA, the National Science Foundation, the intelligence community. We work closely with private industry, state governments, academia, and environmental organizations to carry this out.

But we have to say that our multi-agency cooperation efforts have fallen short in meeting critical national goals. This shortcoming costs the nation in lost ocean potential for societal benefits. It harms the perception of societal justification for the nation's ocean programs. And these effects will grow as the importance of the oceans grows.

The nation's oceans agencies are increasingly constrained by resources. The ocean research budget is declining. For example, ocean research has dropped from about 7 percent to less than 4 percent of federal basic research money in the last 14 years, even as ocean issues have increased in importance and complexity.

In another example, NOAA must be able to go to sea, for everything from research to operations. And yet, our resources for seagoing facilities, whether in-house or contracted out to private industry or academia, are diminishing. There is no certainty that we can gain replacement ship services for less cost.

In the third example, opportunities for NOAA to leverage multibillion dollar defense systems before they degrade or shut down are also being lost. Ocean programs die without ships or aircraft, satellites, buoys, computers or other unique systems.

These are the tools we need to gather data, process it, distribute it, archive it for societal benefit.

NOAA and its other agencies involved in ocean studies are cooperating to keep our programs operational and in the field. But to successfully meet the nation's increasing important ocean needs will require increased support.

Mr. Chairman, my written testimony goes into detail on the cooperative programs that NOAA participates in with the Department of Defense, the academic community and internationally, and I won't try to list those here. They'll be made part of the written testimony.

I'd just like to point out that when I took the job as NOAA administrator, I worked with DOD to strengthen our ties between NOAA and the Department of Defense on oceans programs and satellites in particular and established to help along with our very strong Navy connections and Air Force connection so that we have liaison both with the Air Force and the Navy, and Captain Klein and Colonel McMurrow, who are those liaisons, are here today.

Let me say that there are enormous opportunities. There is much more to be learned about air-sea interaction. There's much more to be learned about building sustainable fisheries. And there's much to be done before we can maximize the use of the oceans for national defense, for transportation, industry and recreation.

We've established coordination mechanisms in the government and we have a variety of these things. But I think one of the things we have learned and one of the things that President Clinton pointed out in his State of the Union address is that the government can't do it all.

We need close cooperation with all the sectors—government, private industry, academic, environmental organizations.

I think one thing we might look at is the successful activity of the President's Council on Sustainable Development, which was a group that was bringing together all of the stakeholders to look at general issues of sustainable development. This group had government representatives from Cabinet agencies, CEOs of major industry, government/nongovernmental organizations and civil rights and labor community representatives.

I believe we could do a similar thing for oceans issues, bringing together government, private industry, the academic community, and the environmental organizations to have a roundtable, a formally established roundtable with each party having a formal seat to talk about how we could provide cohesion and focus to our collective efforts.

We would want to focus this on theme-oriented, top-level discussions that might help move ocean programs more quickly to societal benefits. And we might try to expand these roundtables eventually to include international participation.

I'd like to make two points in particular that we are very concerned about.

One is that NOAA depends very strongly on extramural research. We depend on the academic community for help. When I was working in NOAA as a scientist, I helped establish two joint institutes between the academic community and NOAA. And as administrator, I have strongly supported extramural research.

And I can commit to you that even as we go through budget cuts, we will continue to support the academic community at the same percentage that we do, or even greater as we look at the needs that are there.

The second point is that we have a very successful program of partnership called the Sea Grant Program.

Sea Grant has been a powerful program of partnership between the states, the academic community, and the Federal Government. It has allowed us to do research in important new areas. It has allowed us to make the transition of research to applications.

There are many examples of how that has worked. And I can tell you once again, we are strongly committed to the Sea Grant Program and we will look to continuing that very strong commitment.

Let me close by saying that we believe that the oceans of the world, particularly those close to the coasts, are important to our commerce, to our health, and defense.

I don't think that the situation of declining support is in the national interest and that it should be reversed.

I'd be happy to answer questions. Thanks.

[The prepared statement of Dr. Baker follows:]

4.

TESTIMONY OF

DR. D. JAMES BAKER
UNDER SECRETARY FOR OCEANS AND ATMOSPHERE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE JOINT HEARING

SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT
COMMITTEE ON NATIONAL SECURITY
U.S. HOUSE OF REPRESENTATIVES

SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS
COMMITTEE ON RESOURCES
U.S. HOUSE OF REPRESENTATIVES

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

DATE: JANUARY 25, 1996

Thank you, Messrs. Chairmen and Members of the Subcommittees, for this opportunity to testify about the role played by the National Oceanic and Atmospheric Administration (NOAA) in the Nation's ocean programs. NOAA was formed 25 years ago to serve as a focus for the delivery of a variety of ocean products and services. With such a broad mission, - services, resources, and research -, NOAA has worked closely with many agencies - both national and international -, with private industry, with the academic community, and Mssrs. Chairmen, I might add with Congress, which has shown great interest in ocean issues and provided much useful guidance to all the relevant agencies, to accomplish its work. Today's hearing is a chance to look broadly at the Nation's total oceanographic effort.

The Stratton Commission envisioned that NOAA would provide vital services to industry and the public pursuant to its core mission to describe, monitor, and predict changes in the Earth's environment, to promote the conservation and wise management of the Nation's marine and coastal resources, and to ensure and enhance sustainable economic opportunities. NOAA and its partners have learned much in those efforts and many valuable practical benefits have been achieved. However, the public has yet to reap the full benefit of the Commission's vision. During the past 25 years, the scale and importance of ocean issues has increased dramatically. We have learned much about how the system works and what the pressures are. At the same time, we face decreasing financial resources with which to work.

The oceans are important to the Nation as a driver of weather and climate; as a marine highway to link the United States with the global economy; as a vital source of food, oil and gas, new medicines and other resources for sustainable economic development; as a source of recreational opportunities; as a theater for defense; and as a source of minerals, energy production and biological resources in the future. NOAA works actively with the U.S. Navy, the Departments of State and the Interior, the U.S. Coast Guard, the U.S. Environmental Protection Agency, the U.S. Geological Survey, the Defense Mapping Agency, the National Aeronautics and Space Administration, the National Science Foundation, and the intelligence community. NOAA also works with private industry, states, academia, and environmental organizations.

However, this multi-agency effort falls short in meeting critical national goals. This short-coming costs the Nation in lost ocean potential, and these costs will grow as the importance of the oceans grows. Just three examples to highlight here: The Nation's research budget is declining, and with it the ocean research budget. The ocean science community has not fared well for resources vis-a-vis the research community-at-large. For example, an anylisis by CORE, ocean research has dropped from about 7 percent to less than 4 percent of federal basic research money in the last 14 years, even as ocean issues have increased in importance and complexity. A second point involves our fleet. NOAA must be able to go to sea for everything from research to operations, yet our resources for sea-going facilities, whether in house or contracted out, are diminishing. There is no certainty that NOAA can gain replacement ship services for equal or less cost. In a third example, opportunities for NOAA to leverage multi-billion dollar defense systems before they degrade or are shut down, are being lost.

The opportunities are enormous: There is more to be learned about air-sea interaction; there is more to be learned before we achieve sustainable marine fisheries; and there is much to be done before we can maximize the use of the oceans for transportation, industry, and recreation. Support must be available for the infrastructure required to obtain data, process it, distribute it, and archive it.

During NOAA's quarter century, much has been learned about how the oceans interact with the atmosphere to influence weather and climate. Much has been learned about the limits of marine living resources and about the broad threats that marine ecosystems face. And much has been done to improve the quality of products and services offered to the Nation's ocean users.

NOAA is improving the accuracy of short-term warnings and weather forecasts. For example, NOAA recently inaugurated a new hurricane forecast model that it has been developing for several years. The model is expected to save lives and property for many years to come. NOAA is working to implement seasonal and interannual climate forecasting. For example, data from a new monitoring system in the Pacific Ocean will detect El Nino events and permit seasonal forecasts of its effects. NOAA is contributing to achieve a prediction capability for decadal and even centennial climate change.

The recently completed Tropical Ocean Global Atmosphere (TOGA) project has increased our understanding of seasonal and interannual climate variability. NOAA was a major participant in TOGA, which focused on the tropical Pacific Ocean and which bequeathed a monitoring network, known as the Tropical Atmosphere Ocean (TAO) array. The TAO array is composed of 69 deep-moored buoys which span one-third of earth's circumference, across the tropical Pacific from 95 degrees west to 137 degrees east longitude. NOAA will lead the project to maintain the TAO monitoring array, with participation by Japan, Korea, Taiwan, and France.

Data from the TAO array will give early warning of El Nino events, and will be used in models that have shown predictive capability beyond the tropical Pacific Ocean. For example, recent heavy rains in California and the southeastern United States are largely explicable as an ancillary effect of El Nino/Southern Oscillation - the east-west movement over a period of years of warm surface water between Indonesia and Peru. To derive maximum benefit from continued operation of the TAO array, improvements must be realized in the predictive capability beyond the tropical Pacific. Toward this end, NOAA is working at its Geophysical Fluid Dynamics Laboratory in conjunction with Princeton University and some other federal and international groups that also do environmental modeling. NOAA will also participate in the follow-on Global Ocean-Atmosphere-Land System (GOALS) study, undertaken as part of the Climate Variability and Predictability Programme of the World Climate Research Programme. On the larger time scales, NOAA is involved in the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS).

WOCE

The World Ocean Circulation Experiment (WOCE) is a multi-national effort that will last until 1997. WOCE is designed to learn about large-scale circulation and long-term changes in the ocean. While it is known that the ocean and the atmosphere interact strongly, the feedback mechanisms coupling them are not well understood. For example, it is believed that the oceans can initially act both as a "heat sink" and as a "sink" for greenhouse gases that are taken up in the oceans. As the oceans warm, their ability to hold gases in solution will decrease, but this may be offset by an increase in phytoplankton which take up CO2. Also as the oceans warm, general ocean circulation and mixing, which make the full ocean volume available as a heat and gas "sink", may be altered. The ocean variables are numerous and complex, but they will greatly affect the rate of global warming. Currently, the lack of data and of computing power limit ocean circulation models. NOAA is actively involved in helping to resolve both these limitations.

JGOFS

The Joint Global Ocean Flux Study (JGOFS) is an international effort, involving more than 30 nations, to identify and quantify the movement of carbon between the ocean and the atmosphere. Since continuous measurements of atmospheric carbon dioxide (CO2) began in 1957, the concentration of CO2 has risen from 305 to 357 parts per million by volume. Of the several radiatively important "greenhouse" gases, it is estimated that CO2 will contribute more than half of the global warming effect. But CO2 goes easily into the ocean through biological uptake and solution. Understanding the processes by which CO2 is removed from the atmosphere is important to predicting climate change.

LIVING RESOURCES

Next I would like to focus on programs in which NOAA cooperates with international and national organizations to conserve and manage living marine resources. World fisheries are generally being over-exploited. If this continues it will jeopardize these fisheries as a source of food for a growing world population. The U.S. must work in concert with other nations to promote healthy coastal and marine ecosystems, and to develop sustainable use of ocean and coastal living resources. NOAA has been the technical focus for U.S. development and participation in several treaties. For example, NOAA played a significant role in the negotiation of the recently signed Agreement on Straddling Stocks and Highly Migratory Species which represents an elaboration of the principles set forth in the U.N. Convention on the Law of the Sea (UNCLOS). Also, U.S. leadership was instrumental in bringing about the Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR), which is the first international fisheries agreement that is based on a whole ecosystem fisheries management approach. NOAA has conducted several cruises in Antarctic waters to support this agreement. NOAA was also involved in the development of a regional fisheries agreement for the "Donut Hole" in the Bering Sea, and in getting United Nations acceptance of the moratorium on driftnet fishing on the high seas. A NOAA-Academic partnership in the Bering Sea under NOAA's Coastal Ocean Program provided key scientific information for reaching this agreement. Other examples of international fisheries management agreements in which NOAA is involved are: the International Convention for the Conservation of Atlantic Tunas; the Inter-American Tropical Tuna Commission; the South Pacific Tuna Treaty; the Atlantic and Pacific Salmon Commissions; the North Pacific Anadromous Fish Commission; the International Whaling Commission, the Pacific Halibut Commission, and the MEXUS-Gulf and MEXUS-Pacifico agreements.

NOAA is a leader in the Global Ocean Ecosystem Dynamics (GLOBEC) Research Program, an interagency effort to understand the nature, rate, and causative factors of changes to marine ecosystems and associated fishery resources. Present efforts under GLOBEC are focusing on understanding the role of climate in the problems of Georges Banks fisheries. This effort and a companion Coastal Ocean Program project focused on predation effects are designed to support the recovery, and ultimate sustainability, of Georges Bank fisheries. Future studies are planned off California and in the Bering Sea.

COASTAL PROGRAMS

The United States is blessed with coastal areas of astounding beauty and natural richness. Its bright sandy beaches; its rocky shorelines; its vibrant coral reefs; and its teeming bays, sounds, and marshes are nurseries for valuable fish and shellfish, birds, and other wildlife. However, these coastal areas are also home to a growing human population whose activities stress coastal ecosystems. In multi-agency and intergovernmental cooperation, NOAA is working with federal, state, and local partners to address specific coastal problems in seven geographic regions: Alaska, Pacific Northwest, Pacific Southwest (including Hawaii), Gulf of Mexico, Southeast, Northeast, and Great Lakes. NOAA hopes that this partnership will ensure that our Nation's stewardship of coastal areas and living resources is coordinated, efficient, and successful. The effort is directed to sustaining healthy coastal ecosystems through environmentally-responsible coastal development.

NOAA provides national leadership in the area of coastal zone management by administering the Coastal Zone Management Act in cooperation with both federal and state agencies. NOAA also oversees the National Marine Sanctuary and Estuarine Research Reserve programs which, despite severely limited agency resources, have gained interal recognition as models of integrated management and protection of sensitive marine areas. Also, in cooperation with other federal agencies, NOAA oversees adherence to several international instruments, including the

International Convention on the Prevention of Pollution from Ships (MARPOL); the International Convention on the Prevention of Wastes and Other Matter (the London Convention), and customary international law as reflected in the 1982 Law of the Sea Convention. Pursuant to its statutory authority under the Ocean Dumping Act, NOAA conducts a program for monitoring and assessment of the condition of dumpsites and, in conjunction with other federal agencies, participates in formulating U.S. positions for the London Convention which regulates ocean dumping on the international level.

NOAA's Coastal Ocean Program is supporting Federal-academic research partnerships for assessing and predicting the effects of multiple stresses in coastal environments, including the Florida Keys, Florida Bay, the Chesapeake Bay, coastal Louisiana, the Great Lakes, the Pacific northwest, and Long Island. NOAA's Coastwatch program provides coastal users with timely ocean remote sensed data. NOAA is also a partner in the Coastal America Program that is taking action to deal with problems such as coastal habitat degradation and loss, nonpoint source pollution, and contaminated sediments.

NAVIGATIONAL ISSUES

The oceans are a significant part of the world's highways, and increasingly so. Shipping accounts for over 95% of the U.S. international trade--a rapidly growing sector of this Nation's economy. In turn, issues involving navigation, safety, and protection of the marine environment become more crucial. With respect to navigation, in fulfilling its statutory responsibility for surveying and preparing the nautical charts of the Nation's coastal waters, NOAA works in coordination with several agencies, including the U.S. Coast Guard, the Defense Mapping Agency, and the Departments of State and the Interior. NOAA is expanding the use of private contract resources to conduct new hydrographic surveys of our port and harbor approach areas to replace surveys that are more than 50 years old. NOAA is also working with the Coast Guard, the maritime community and private sector partners to develop a new generation of navigation products based on electronic chart technologies. The first of these products, digital raster charts, produced and distributed by the private sector, are now available for most U.S. waters.

Also, NOAA is a member of the Baseline Committee, an interagency group that addresses the ongoing questions involving depiction of the U.S. baselines used to determine our international marine boundaries. NOAA also worked with the Coast Guard, and Departments of Defense and State to provide for the ability to implement systems for mandatory reporting and routing of vessels. As part of its damage assessment program, NOAA works closely with other agencies such as the Coast Guard in carrying out its marine resource trusteeship responsibilities set forth in the Oil Pollution Act. NOAA also coordinates enforcement efforts with the Coast Guard not only in the area of fisheries enforcement, but also with respect to marine sanctuaries. Coordinated efforts such as these contribute greatly to safety of life at sea, the safety and efficiency of navigation, and the protection of the marine environment.

NATIONAL SEA GRANT COLLEGE PROGRAM

The National Sea Grant College Program, managed by NOAA's Office of Oceanic and Atmospheric Research, is a network of over 3,000 scientists, engineers, educators, students, and outreach specialists in over 300 institutions nation-wide. The Sea Grant Program supports university-based research, education, and technology transfer to support the needs of people, industry, and governments concerned with coastal, ocean, and Great Lakes issues. From dealing with the Zebra Mussel, to improving genetic strains for aquaculture and investigating the pharmaceutical potential of diverse marine life, the Sea Grant Program binds academia and government to investigate techniques for deriving sustained benefit from the oceans. The common goal of the Sea Grant program at all educational institutions is to provide educators with insights into contemporary marine and aquatic issues, and to provide the strategies to bring information on these issues to students. For example, Operation Pathfinder is a program to provide curricular training in oceanography and coastal processes, during 12-day summer sessions, to elementary and middle-school teachers. To foster technology transfer to industry, the Sea Grant Industrial Fellows Program began this year as a trial effort, with seven graduate students selected to collaborate for closer corporate/school ties.

NURP

NOAA's Undersea Research Program (NURP) is dedicated to coordinating and supporting safe in-situ marine and large lake research using the most modern tools available, including manned submersibles, air and mixed gas diving, remotely operated vehicles, and undersea habitats. In this effort, NOAA relies heavily on U.S. Navy assets to support principal investigators in civil studies related to: undersea biological productivity and recruitment, coastal oceanic and estuarine processes, pathways and fates of contaminant material, mineral resources, ocean technology, and diving safety and physiology. For example, NOAA has cooperated with the Navy in the use of DSV TURTLE; DSV SEA CLIFF; the DSRV ALVIN; the unmanned Advanced Tethered Vehicle; and the nuclear submarines NR-1, USS PARGO, and USS CAVALLA. Since 1993, over $950 thousand has been transferred from NURP to the Navy to cover part of the cost of using these vehicles for civil ocean research. NURP is the U.S. representative under the

United States-Japan Cooperative Program in Natural Resources, which includes the use of SHINKAI 2000 and SHINKAI 6500 - presently the world's deepest diving capability.

There are six regional Undersea Research Centers, associated with marine schools, that carry out the NURP mission: the Northeast and Great Lakes (University of Connecticut, Avery Point); the Mid-Atlantic Bight (Rutgers University); the Southeast and Gulf of Mexico (University of North Carolina, Wilmington); the Caribbean (Florida State University, University of South Carolina, Oregon State University, College of William and Mary-Virginia Institute of Marine Science); West Coast and Alaska (University of Alaska, Fairbanks); and Hawaii/Western Pacific (University of Hawaii, Manoa). Investigators from 108 colleges and universities, and 31 state and federal agencies participated in 670 manned submersible dives, 360 remotely operated vehicle dives, and over 12,000 mixed gas dives conducted with NURP support in 1994. There were no serious accidents during these activities.

NOAA SATELLITE OCEANOGRAPHIC REMOTE SENSING (NSORS)

Through the National Environmental Data and Information Service (NESDIS), NOAA operates the world's largest constellation of environmental observation satellites. Although the NOAA Polar-orbiting Operational Environmental Satellites (POES) and Geostationary-orbiting Operational Environmental Satellites (GOES) were designed primarily as meteorological satellites and their sensor suites are, therefore, optimized for weather observations, warning and predictions, these satellites are global observing systems and have several important applications in ocean monitoring.

A program is under development within NESDIS to exploit the very large financial investment in oceanographic satellites being made by the U.S., European nations and Japan. This effort is called the NOAA Satellite Ocean Remote Sensing (NSORS) initiative. NSORS will provide an opportunity to access oceanographic data from non-NOAA spacecraft, create products and services based on those data, and distribute data and data products to users, including use of the NOAA CoastWatch program. NSORS has four principal thrusts: 1) all-weather sea/ice/land observations, 2)multispectral ocean color measurements, 3) wind direction and speed observations, and 4) utilization of un-classified data to enhance existing civil capabilities.

JOINT INSTITUTES

The Office of Oceanic and Atmospheric Research supports 10 Joint

Institutes of which 6 deal with the oceans. These Joint Institutes combine the resources of NOAA's eleven Environmental Research Laboratories with selected universities. The intent of the Joint Institutes is to form centers of excellence in specialized fields. Joint Institutes are a mechanism for technology development and technology transfer to the private sector. The ocean-related Joint Institutes are: the Cooperative Institute for Arctic Research (CIFAR) with the University of Alaska-Fairbanks; the Cooperative Institute for Marine and Atmospheric Studies (CIMAS) with the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences; the Joint Institute for Marine and Atmospheric Research (JIMAR) with the University of Hawaii; the Joint Institute for Study of the Atmosphere and Ocean (JISAO) with the University of Washington; the Atmospheric and Oceanic Sciences Program (AOSP) with Princeton University; and the Cooperative Institute for Marine Resources Studies (CIMRS) with Oregon State University.

NOAA COOPERATION WITH THE DEPARTMENT OF DEFENSE

Now I would like to focus on NOAA's cooperation with the Department of Defense (DoD). NOAA's predecessors, the U.S. Weather Bureau and the U.S. Coast and Geodetic Survey, were associated with the armed forces in meteorological services and nautical charting almost from the start of the country. Cooperation to carry out these functions continues today. In addition, since the end of the Cold War, opportunities have arisen for the civil use of defense and intelligence systems, and for the civil use of environmental data acquired for defense purposes. In general, these systems and data sets are unique, because the civilian agencies could never hope to duplicate them on their own. NOAA has been one of the most pro-active agencies in seeking opportunities for civilian access to defense systems and data. But resource incommensurability has inhibited progress.

IUSS

Following the Cold War, the U.S. Navy sought to restructure its strategic anti-submarine warfare system - the Integrated Undersea Surveillance System (IUSS). This restructuring was driven by the relative decline in the "blue water" submarine threat and the increase in the coastal "brown water" submarine threat. The oldest component of the IUSS is the Sound Surveillance System (SOSUS), which is a network of fixed, passive-listening hydrophones that are most effective in the "blue water" arena. Navy has deactivated serveral SOSIS arrays Some scientists without security clearances are aware of the capability of the SOSUS arrays to monitor whale vocalizations, to detect natural underwater seismic noises, to assist in fisheries enforcement in international waters, and to conduct long-path ocean temperature measurements that will be a key indicator of climate change. (The latter is accomplished by precise determination of transmission time for low-frequency acoustic signals). The value of SOSUS data to advance marine mammal studies, sea-floor studies (such as hydrothermal venting, volcanic activity, sea-floor spreading, and earthquake research), climate change studies, and fishing enforcement is clear. The Navy has allowed NOAA scientists access to SOSUS data from arrays that the Navy continues to operate in support of their mission. For example, Dr. Christopher Fox, with NOAA's Pacific Marine Environmental Laboratory, won a 1994 Department of Commerce Gold Medal for his work using SOSUS data from an array off the Washington/Oregon coast. However, another array in Bermuda, which had great potential for marine mammal studies in the North Atlantic, has been closed. The Navy took caution to close the facility in a manner that will permit future access. NOAA is now working other groups to permit reactivating the Bermuda SOSUS array for scientific use. Success in this endeavor will depend upon funding of arrays and implamenting of security screening procedures prior to release of the data.

An interagency working group on IUSS Dual Use, in which NOAA participated, was chaired by an official from the Office of the Director of Defense Research and Engineering. The group issued a report in December, 1994 that found scientific utility in the IUSS, especially the SOSUS. It recommended a 3-5 year focused research effort to develop this scientific value. However, it found that civil agencies participating in the study would not fund long-term operation of SOSUS arrays no longer needed by the Navy. The scientific use of SOSUS has been a limited success. The Navy has been cooperative where it has maintained arrays; the scientific value of SOSUS data has been proven; and much valuable scientific work has been accomplished already. However, where SOSS arrays have been shut down, as in Bermuda, they will degrade in an unpowered condition and a unique opportunity to gather scientific data by leveraging a multi-billion dollar defense investment will be lost.

OTH-B

Following the Cold War, the U.S. Air Force had no mission requirement for two multi-billion dollar Over-The-Horizon - Backscatter (OTH-B) radars, located in California and Maine. These powerful radars achieve great detection ranges by bouncing high-frequency radio waves off the ionosphere. For example, the east coast radar can look across the Atlantic to Europe, North Africa and northern South America. The west coast radar can look over the entire Aleutian Islands and past Hawaii. Designed to detect aircraft, the radars can also detect sea-surface conditions and the radial component of ocean surface current. From sea surface conditions, wind field patterns over the entire

North Atlantic and North Pacific Oceans can be derived. The Air Force permitted Dr. Tom Georges, with NOAA's Environmental Technology Laboratory, to use the east coast OTH-B radar for research. Using the radar, Dr. Georges provided information to NOAA's National Hurricane Center (NHC) on wind fields associated with hurricanes during part of the 1994 and 1995 hurricane seasons. NHC's analysis was that the data was a valuable addition to information from satellites to forecast hurricanes. It provided a continuous, broad area presentation of changing surface wind direction not available from satellite data. Both the east and west coast OTH-B radars have now been shut down. But the Air Force is investigating letting Dr. Georges continue his research on an Australian OTH-B radar, as part of a Memorandum of Agreement between the U.S. and Australian Air Forces.

ROTHRs

The U.S. Navy still operates ionospheric backscatter radars in support of the counter-drug mission for the Caribbean and Gulf of Mexico region. Called Relocatable Over-The-Horizon Radars (ROTHRs), these radars do not possess the immense range and area coverage of the Air Force OTH-B radars, but they offer the unique advantage of parallactic data from two radars - one located in Virginia and one in Texas. (A third radar may be opened in Puerto Rico.) The Navy has permitted Dr. Georges to work with the radars on a not-to-interfere basis with the primary mission. In addition to wind field information over the Caribbean and Gulf of Mexico that is useful to the National Hurricane Center, Dr. Georges has demonstrated the ability to generate surface current vectors that are useful to the U.S. Coast Guard in search and rescue efforts and in predicting oil spill trajectories. In the future, Dr. Georges would like for his work to be designated a secondary mission for the radars, but doing so would make NOAA responsible for a share of operating costs - a financial burden that NOAA cannot accept.

WORK WITH THE NAVY

NOAA cooperates closely with the Navy, as evidenced by the 24 Memoranda of Understanding (MOUs) and Memoranda of Agreement (MOAs) now in effect. Here are a few examples of our cooperation with the Navy. The National Ice Center in Suitland, Maryland is operated jointly by NOAA and the Navy to provide ice forecasts for the safety of mariners and for high latitude operations. NOAA and the Navy cooperate for meteorological forecasting in the Pacific - especially for typhoon warnings. We also cooperate in areas as diverse as environmental modeling, supercomputing capability, oceanographic data archiving (at NOAA's National Oceanographic Data Center), the use of undersea craft, shared processing of satellite data, ocean science research with the

Naval Postgraduate School, logistic support for operations in connection with the MONITOR Marine Sanctuary, and the collection of information to support NOAA's real-time navigational information systems.

DEFENSE HYDROGRAPHIC INITIATIVE

The Defense Hydrographic Initiative (DHI) was established by formal charter on June 20, 1991 to coordinate hydrographic and bathymetric mapping among the Defense Mapping Agency (DMA), the Oceanographer of the Navy (N096), and NOAA's National Ocean Service. It is a real success story. The DHI has leveraged federal resources by developing a common approach to the assessment of errors associated with bathymetric data, by completing the design of a data collection system that will permit ship-of-opportunity data collection (including ships from academia, industry, Navy, DMA, NOAA, and abroad), and by development of a Hydrographic Source Assessment System (HYSAS). These developments will lead to a master sea-floor digital database that will contain the highest quality sea-floor data, and that will be accessible for scientific research, sea-floor engineering, environmental assessment, and marine navigation applications.

SUBMARINE ARCTIC SCIENCE CRUISES

The multi-agency MOA regarding the use of nuclear submarines to accomplish scientific research in the Arctic Ocean epitomizes how dual-use should work. The Navy desires to retain an operational capability in the Arctic, and to increase its scientific understanding of the environment in which it must operate. Toward this end, the Office of Naval Research (ONR) invited civilian scientists to work with scientists at the Navy Arctic Research Laboratory. Navy initiated the MOA for a Submarine Arctic Science Cruise Program (SCICEX). The MOA was signed by Navy, NOAA, the National Science Foundation, and the U.S. Geological Survey in June, 1994. Two cruises, one by the USS PARGO and one by the USS CAVALLA, have already been completed and planning for SCICEX-96 is well along. Dr. Ted DeLaca, Director of the Office of Arctic Research at the University of Alaska, with which NOAA has the Cooperative Institute for Arctic Research, was the chief scientist for both cruises. The crews of the submarines were extremely supportive of the civilian scientists, and all scientific data was declassified shortly upon completion of the cruises making it available to the scientific community-at-large. Already, significant new findings have been made that influence geological, geophysical, biological, and oceanographic thinking about the Arctic region. On their own, the civil agencies could never have duplicated the capability offered by the Navy's nuclear submarines. Prior to each cruise, a Science Steering Committee, composed of a member from each signatory agency to the MOA, screens invited scientific proposals for participation. The Navy asks only that agencies sponsor principal investigators with contributory funding related to the cost of their scientific equipment and data handling.

HYDICE

NOAA is participating in an MOU with the Central Intelligence Agency (CIA) and several other agencies to design, test, and exploit an unclassified, advanced, airborne, electro-optical remote sensing instrument with ocean measuring capability. This project, called the Hyperspectral Digital Imaging Collection Experiment (HYDICE), is being headed by the Naval Research Laboratory (NRL). A prototype HYDICE instrument has been completed and in-flight testing is well underway. From early flight data, representatives from participating agencies, all experts in different applications of remotely sensed information, agree that HYDICE will have both civilian and military applications. The participating civilian agencies will gain access to hyperspectral data from an unclassified system that they could never afford to develop on their own. HYDICE data will be useful to NOAA for such missions as sustaining coastal ecosystem health, and discussion is underway to fly HYDICE on NOAA aircraft.

ACTIVE LIAISON

The NOAA Corps is an effective cadre promoting NOAA's liaison with other agencies, especially DoD and the intelligence community. For example, NOAA officers are assigned to liaison with the Oceanographer of the Navy (N096), the Naval Meteorology and Oceanography Command (NMOC), the Naval Postgraduate School (NPS), the Defense Mapping Agency (DMA), the National Ice Center (NIC), the National Polar Orbiting Satellite Convergence Office, the Central Intelligence Agency (CIA), and the U.S. Coast Guard. One officer is assigned specifically to coordinate NOAA access to military and intelligence systems. The NOAA fleet, operated by the Office of NOAA Corps Operations, has acquired two ships from the Navy. These ships are the T-AGOS ships RELENTLESS and TITAN that were previously operated as part of the U.S. Navy's Integrated Undersea Surveillance System.

WORK WITH THE AIR FORCE - GPS

NOAA further has advanced ocean studies through its cooperation with the U.S. Air Force and the Defense Mapping Agency. The Air Force operates the Global Positioning System (GPS) and NOAA was one of the first civil agencies to be granted access to its classified, very precise P-code. Using GPS P-code for horizontal control has permitted NOAA to minimize its reliance on geodetic shore control and expensive, specially-deployed medium-frequency radio-positioning systems. NOAA is now capable of more productive, more precise, and less expensive bathymetric and hydrographic surveys. The GPS-P has also increased NOAA's ability to reoccupy ocean sites. For example, using precise positioning together with remotely-operated tethered vehicles, NOAA can recover instruments left for months near hydrothermal vents or in sea-floor boreholes. Captain Lewis Lapine, a NOAA officer who heads NOAA's National Geodetic Survey Division, is chairman of the GPS Interagency Advisory Council. He also participates in an Office of Science and Technology Policy Interagency Working Group to develop a Presidential Policy Directive that will set the tone for acceptance of GPS as the worldwide positioning standard.

POLAR-ORBITING METEOROLOGICAL SATELLITE CONVERGENCE

NOAA and the Air Force are now engaged in the long-term convergence of the Defense Meteorological Satellite Program (DMSP) and the NOAA Polar-orbiting Environmental Satellite Program. Combining these two weather satellite programs into one system is expected to save up to one billion dollars by the year 2006. The combined system, to be operated by NOAA, is called the National Polar-orbiting Operational Environmental Satellite System (NPOESS). NPOESS is headed at NOAA by a newly retired Air Force colonel, James T. Mannen, with a NOAA Corps captain as his executive officer. NASA and the Navy are also involved in shaping the NPOESS that will evolve from the present constellation of two NOAA and two DMSP satellites. Additionally, outside advice is being sought on the design for replacement satellites. The interests of ocean scientists will be protected. New NPOESS satellites will build on NOAA's present ocean remote sensing program and will be at least as capable as present satellites of measuring ocean parameters, including sea ice cover and icebergs, cloud cover, sea condition, wind velocity, and sea surface temperature.

JOINT-TENANT COMMAND AT MACDILL AIR FORCE BASE

The NOAA Aircraft Operations Center, from which NOAA flies its hurricane research and other missions, is a joint-tenant command at MacDill Air Force Base, near Tampa, Florida. This agreement with the Air Force realizes great cost savings for NOAA over its previous facilities at the Miami International Airport.

NOAA COOPERATION WITH THE INTELLIGENCE COMMUNITY

NOAA scientists participated in the Environmental Task Force (ETF) formed by then-Senator Gore and Senator Nunn. And NOAA has continued working with the follow-ons to ETF - the MEDEA project and the Government Applications Task Force (GATF). As part of the MEDEA project, Rear Admiral Paul Gaffney, Commander of the Naval Meteorology and Oceanography Command, supported a study released in June 1995 about the scientific utility of environmental data gathered and archived by the Navy. As a result of his and MEDEA's efforts, many classified data sets were identified as useful to the civilian ocean community. Now these data sets are being reviewed for possible declassification, and some data has already been released. These data, and other ocean data which are to be declassified are, and will be, available through NOAA's National Oceanographic Data Center. For example, beginning in March, 1985 the Navy carried out an 18-month, $80 million project (the GEOSAT Mission) to measure gravity from space as a means of improving the accuracy of submarine-launched ballistic missiles. It was discovered that perturbations in the gravity field over the oceans could reveal sea-floor topographic features. (The gravitational influence of these masses also produces variations in local sea level that can be measured by satellite-borne radar altimeters.) Following the study, the Navy released worldwide GEOSAT data and NOAA scientists, working with scientists from Scripps Institution of Oceanography, compiled GEOSAT data with data from other sources to produce an impressive 12 x 8 foot, multicolored map that shows previously unknown geological features over the 71 percent of the earth's surface covered by water. The map is a major advance in our understanding of the oceans, and it may force revision of plate tectonic theory, because plates making up the earth's crust do not appear to be as rigid as previously thought. NOAA scientists may benefit from other data sets if they are declassified, such as: sea ice (historical morphology and keel depths), salinity and temperature with depth profiles (real-time and archived), ocean optics and bioluminescence, geomagnetics, and sea-floor sediment (thickness and type). These data sets will be available through NOAA's National Oceanographic Data Center and National Geophysical Data Center.

NOAA established an early relationship with the intelligence community for the use of national technical means (NTM) imagery to assist in shoreline delineation for coastal mapping. The use of NTM imagery has expanded into other proper use applications for NOAA. In order to facilitate NOAA's access to NTM imagery, an officer represents NOAA on the Civil Applications Committee which is the civilian interface with the intelligence community.

CONCLUSION

I thank you again for this opportunity to relate how NOAA is working in concert with the national and international ocean community to increase knowledge of and benefits from the oceans. No other agency has such a broad responsibility for research, measurement, monitoring, and the delivery of products and services related to the oceans as does NOAA. This work has large costs and widely dispersed benefits. But the benefits are real. NOAA's work enhances future opportunities for U.S. citizens, promotes a healthy U.S. economy, protects our environment, and fosters the sustainable use of our natural resources. What are the next steps? I believe that we need action now, and am prepared to sit down with our partners in government, Congress, private industry and academia to set priorities. Jack Botzan says that we are in the third wave of oceanography, and new partnerships are the key. I strongly support that, and want to help make it happen.

I mentioned earlier that the Nation has benefited from the vision of the Stratton Commission 25 years ago, but that a full realization of that vision can only come about through a renewed commitment to the development of a coherent national ocean agenda. I also mentioned that ocean issues are more critical now than they were 25 years ago. The critical resources of the ocean are being depleted, and there is much to learn about the role of the oceans in regulating climate.

Rightfully, Congress is struggling to reduce or eliminate the federal budget deficit and not burden future generations with debt. Yet I urge Congress to ensure that we do not, in the process of correcting fiscal woes, burden future generations with other grave problems that can only be prevented by sound investments to build the foundation for sustainable development. Knowledge and understanding of the oceans will be vital to their ability to solve problems they will encounter in the 21st Century. I believe that Congress, federal agencies, state agencies, academia, and non-governmental organizations must work together to improve our vision of and infrastructure to deal with ocean issues. Beyond that, we must work jointly to execute this vision in furtherance of the national defense and the general welfare of our Nation.

Thank you, Messrs. Chairmen. This concludes my testimony. I will be pleased to answer any questions you may have.

Mr. WELDON. Thank you, Dr. Baker.

Admiral Boorda, I guess you get the prize for the witness coming the longest distance. You flew in from California, I understand.

We deeply appreciate your commitment to be here.

STATEMENT OF ADMIRAL JEREMY M. BOORDA, USN CHIEF OF NAVAL OPERATIONS, DEPARTMENT OF THE NAVY

Admiral BOORDA. I did. I was in San Diego and Orange County last night, after the State of the Union address the night before.

Mr. WELDON. Welcome.

Admiral BOORDA. And I think—I'm not sure. Is it lunchtime or dinnertime?

It's one of those.

[Laughter.]

Mr. Chairman, and chairmen of the other subcommittees and members, I'm happy to be here. I have a statement for the record. It's rather detailed. I'd like to summarize that.

Even my summary will be detailed because, in the past year, we have reviewed our operations, our science and technology, and our cooperation with other agencies in a very careful and I think focused way.

And so, we have a direction that we are headed in. I want to try to explain that and see if it meets with the common sense test from the Congress. And I think we have pretty good agreement among us that we're headed off in a good direction.

I think the simple fact that you would ask the Chief of the Navy, not a technical expert in this area, but, rather, the Chief of Naval Operations, to testify, and that we would have this kind of arrangement, sends an awful strong signal, and I think it's a good one.

Our Navy, as we have changed our strategy following the end of the Cold War, the demise of the Soviet Union and the Warsaw Pact have also changed some of the things we do in the field we're talking about today, and I'll try to be explicit about that in just a moment because it's important in how we use our resources and what kind of information we gather and what is available to the rest of the scientific community.

Because I'm not a technical expert in this field and don't pretend to be, and because they're vitally interested in the programs because they run them, I brought the leaders of Naval Oceanography with me today.

The Chief of Naval Research is an admiral, Rear Admiral Marc Pelaez, and he provides in our Navy the direction for ocean science and technology and development, about $150 million a year program, along with he does S&T and all the other areas as well, but this is a key area of interest for him and for us.

The Oceanographer for the Navy, also sitting behind me on my left, is Rear Admiral George Davis. He manages the resources and the policies for the programs we're talking about today. He's the Washington guy who gets the resources and then allocates them or completes the allocation within our department.

I might add that George will retire at the end of this month, after more than 35 years of service to our nation, really good service, and we're going to miss him. He will be replaced by Rear Admiral Paul Tobin, who is very well qualified for the job. But it's going to be a tough job relieving George Davis.

I wanted to get that in the record and I hope you don't mind.

Mr. WELDON. Without a doubt, we don't mind. We note that for the record and we extend our best wishes for the outstanding, exemplary career that has been provided for the people of this country.

Admiral BOORDA. Thank you, Mr. Chairman. And then on my left is Commander of the Naval Meteorology and Oceanographer Command, Rear Admiral Paul Gaffney. He is an expert with a career in oceanography.

He directs our operational day-to-day programs. He is a direct interface with most of the people you're hearing from.

Our program is wide-ranging because of our mission. It includes traditional oceanography, meteorology, weather forecasting, mapping, charting, geodesy, astronomy, and also positions of stars and precise timing, all those things which we need to carry out a naval mission in defense.

We need that information about the world's oceans, the deep oceans. But we also need it in the littoral areas and in the atmosphere above them because this is our operating environment. This is where we do our business.

A full understanding of the maritime environment is absolutely necessary for the success of any modern naval mission.

The high-tech systems we use in the Navy today require sophisticated and timely environmental information or they won't work. And we need that information to support go or no-go decisions by operators such as myself and for the precise use of weapons, so that the weapons go where we want them to go, hit the target, and do not cause collateral damage.

I chair something called the CNO Executive Board. I'll call it a CEB for the rest of today—CEB—but CNO Executive Board, which overseas Navy policy and major Navy funding issues. In that board, as Admiral Watkins will well remember, the CNO makes decisions based on the best information he can get, which then become recommendations within DOD to the Secretary of the Navy, Secretary of Defense, and eventually, if approved, end up here.

Last June, I convened such a special CEB, or CNO Executive Board, to review our progress, potential and planning for naval oceanography. That review reaffirmed just how important oceanography is to naval operations, but it also did some other things.

It highlighted how much more difficult our job in oceanography is now, now that we are focusing on a much more complex environment, the littoral areas of the world.

Here, where the land and the sea and the seafloor all interact, changes in the environment are created on very much shorter time scales than in the deep ocean areas.

Our job is much more difficult now.

Based on that CEB, on that board, I decided to do the following things.

One, to increase federal, academic and industrial partnership. Not to talk about increasing them, but to increase them.

Two, to help start a National Oceanographic Facilities Council where we, the Navy, would play an important role because of our resources and because of the importance of the data.

To maintain a Navy survey fleet of no less than eight ships. We had 12. We were going to be smaller. Once George Davis and I and my other advisers looked at the problem, we said that in our allocation of resources, eight was the bottom line, or we wouldn't do a good job and our war-fighting missions would then suffer.

So eight is the number we settled upon. And we have taken action to make that possible.

We said—I said—that we would develop new ways of collecting and processing data more quickly. You heard the witnesses that went before me plead for that, and we need to do that, too, not only to share with them, but for our own purposes in defense.

To stay in the forefront of large-scale computer capability. That's important to the Navy and to any military for lots of reasons, but particularly here, where we're dealing with a much more complex environment now as we get closer to land and need the ability to deal with that and understand it.

To establish some real, not discuss them, but establish some real ocean areas as natural laboratories, to test new ideas and technologies in the areas that we are concerned about.

So we establish some test areas and then try to extrapolate that to other areas of the world.

Very importantly, I decided that in my budget recommendations from here on out, while I'm the chief, to keep our ocean research funding to at least its current level, to not succumb to the temptation to salami-slice it down along with everything else.

And to re-establish Navy-funded research chairs at appropriate oceanography and academic institutions to improve our ties with those institutions on an everyday basis.

My written statement outlines the structure of our ocean research activities and our operational oceanography program. But this morning, I'd like to focus on only one thing that came out of that CEB, and that is the partnerships because the very people that we are forming these partnerships with are here today.

The idea of partnerships is not new to the Navy and it's not new to Navy oceanography. All aspects of our oceans program involve cooperative efforts. To do otherwise would be to waste the government's money and to miss opportunities to know about things we must know about.

The overwhelming majority of the environmental data we use on a daily basis to support our operations comes from national and international civil organizations. Most people would think it was just the opposite, that we collected most of the data on our own.

That is not the case.

In return, though, because we do collect a lot of data, over 90 percent of the Navy-collected data is made available to the public, much of it in real time.

Let me say that again.

Most of our information comes from elsewhere and almost all our information goes back in return. But not all, and that of course is a subject we'll want to talk about.

Tax dollars invested in naval oceanography support the public through development of new technologies, research ships and submersibles, important to us because the data is coming back to us, and through overseas nautical charts, typhoon warnings, ice forecasts, our weather and ocean databases. And we also support civilian research operations and environmental studies.

Let me just mention a few unique, very specific partnerships that make the point about what I'm talking about.

NonNavy researchers—NonNavy researchers—are getting unprecedented access to the Arctic by going under the ice once a year in our operational submarines. Scientists going to sea with us under the idea with special configurations in the submarines to actually do their work in a submarine that was built for a very different purpose.

One short demonstration project using Navy's underwater surveillance system for tracking whales, something we could do, even as we did other jobs that those systems were designed for, apparently provided, at least I'm told this, more information on marine mammal movements than all the previous data collected in the history of any effort at all.

One short experiment.

DOD, NASA—as the Doctor just said—DOD, NASA and NOAA are converging the military and civilian environmental satellites—I love the way we talk. We're putting them together under one agency. I think that means we're converging them.

[Laughter.]

I didn't learn any of that at the University of Rhode Island, Mr. Kennedy. I just learned to say that we're putting them together.

[Laughter.]

But we're putting them together into one program that will be much more cost efficient and will let us share data in a very easy and efficient way.

The Oceanographer of our Navy, George, and the National Geographic Society take high school students to sea, and their teachers, too, very selected people. I just had a delightful time with a teacher and spent some time providing information to children in something called MARCO POLO, a few weeks at sea in an area where they learn about oceanography, give that information to other schools, and they also learn a little bit about history and their country from people who really know what they're talking about.

I'm particularly pleased with our participating in the Environmental Task Force, and in MEDEA. These scientists are demonstrating unique research capabilities using Navy systems and Navy data sets and we're working to declassify as much environmental information as we can.

The Navy is committed to an active partnership with you and with the rest of the national oceans community to ensure that we remain a world leader in the field because we need to do that to do our job.

In closing, I want to assure you that as much public access to our data and our systems as possible is our goal. But—and it's an important "but"—in some areas, such as continued operation of parts of the social system, those parts no longer needed for Navy use, or costly adaptation of classified data sets for public release, there are unresolved issues.

We aren't finished yet. And we need to work those issues in a cooperative way. That's the signal I'm trying to send you by being here today.

We look forward to working with the Congress and to working with the other agencies to realize the full potential of those opportunities.

That concludes my formal remarks. I obviously have much more detail in my statement.

Thank you.

[The prepared statement of Admiral Boorda follows:]

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NATIONAL SECURITY COMMITTEE

WRITTEN STATEMENT OF

ADMIRAL JEREMY M. BOORDA, U.S. NAVY
CHIEF OF NAVAL OPERATIONS

BEFORE THE JOINT HEARING

SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT
COMMITTEE ON NATIONAL SECURITY
U.S. HOUSE OF REPRESENTATIVES

SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS
COMMITTEE ON NATURAL RESOURCES
U.S. HOUSE OF REPRESENTATIVES

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

ON

DUAL-USE

OCEANOGRAPHIC PARTNERSHIPS

25 JANUARY 1996

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NATIONAL SECURITY COMMITTEE

Throughout this nation's history, oceanography has been an important contributor to successful Naval operations, and will be increasingly important in the future. By the nature of its mission, Navy must be a leader in ocean research and programs describing its operating environment. Partnerships in oceanography between Navy, other Federal agencies, academia, and industry improve not only Navy capabilities, but support many civil applications as well. This statement addresses the reasons oceanography is essential to Naval operations, why Navy leadership in this area is critical, and discusses the importance of cooperation in ocean activities.

As an island nation, protected from adversaries and linked to partners by the world's great oceans, it is fundamental that the United States understand the surrounding marine environment. Similarly, the United States Navy, a global navy, must understand the global environment in which it trains and operates. The need to deal with the maritime environment is one of the fundamental factors that separates navies from armies and air forces. To be successful a modern navy requires the very best knowledge of oceanography and its related sciences.

Naval oceanography embraces research, technology and operational programs not only in traditional oceanography, but also in meteorology, mapping, charting and geodesy, astrometry (the positions of celestial bodies), and precise time. Navy's oceanography program is led by three flag officers. The Chief of Naval Research, RADM Marc Pelaez, oversees the long term direction for ocean science and technology development. The Oceanographer of the Navy, RADM George Davis, directs resources and policies for the operational oceanography program. Commander, Naval Meteorology and Oceanography Command, RADM Paul Gaffney, runs the operational program and provides all day-to-day operational support to the fleet.

The ocean and atmosphere affect all aspects of Naval warfare. The ocean's density structure affects the use of sonars just as the structure of the atmosphere affects radar performance. Amphibious, mine, and special warfare all require rapid, accurate environmental information to support modern contingency operations. Modern military operations require accurate positioning, navigation, and time information. Today's high-tech weaponry increasingly requires sophisticated environmental inputs for "GO/NO-GO" decisions and optimal performance, and to support the precision required to hit the target while avoiding collateral damage to non-military structures.

Throughout much of the last half century, Navy concentrated its efforts on the open ocean, or "blue water," battlespace of the Cold War. But, as reflected in Department of the Navy landmark white papers, "... From the Sea" and "Forward ... From the Sea," the era ushered in by the end of the Cold War requires a new focus on the more complex and rapidly changing littoral regions of the world.

CNO Executive Board

The Chief of Naval Operations Executive Board (CEB), a Navy leadership group which analyzes Navy requirements, convened last June to review the status of Navy's Oceanography program and to examine new requirements and directions for the future. The review by the CEB reaffirmed the continuing -- and increasing -- importance of oceanography to naval operations. To emphasize this point, a Chief of Naval Operations policy statement was issued that underscores the new focus on Naval Oceanography:

> "Understanding the oceans is fundamental to our national security as well as to global economic and environmental well-being. A robust competency in oceanography is a core requirement and responsibility of the U.S. Navy, one so vital to the success of our operations that we must lead in focusing national attention on ocean policy and programs."

The CEB also highlighted another important point. In retrospect when we concentrated our efforts away from the littorals, understanding the open oceans was relatively simple -- with operating areas that are deep, distant from land, ruled by large-scale, fairly simple physical processes, and comprised of features that change slowly, over days and weeks. Decades of high quality science and technology, together with operational experience, resulted in development of impressive proficiency in forecasting and adapting to the deep water environment. Navy became a world leader in the field.

Naval operations in the world's littoral areas, however, present a host of new challenges: complicated terrain above and below the water; the land-sea interface; smaller ocean and atmospheric features that change more rapidly -- in days to hours, perhaps even minutes. All these have a greater effect on sensors, weapons, and operations than is the case in the deep ocean environment. The littoral environment requires new and better sensors to collect data faster -- sometimes from denied areas. Additionally, more computing power is required to transform the data into useable products, and more efficient communications are needed to rapidly move the information to deployed forces.

To address these challenges, the CEB endorsed a number of objectives. Navy will:

- Encourage enhanced cooperation among the Federal agencies, academia, industry, and international organizations in oceanography;
- Take the lead in organizing an interagency National Oceanographic Facilities Council, to coordinate the best use of the nation's oceanography assets;
- Preserve a robust "at-sea" research and survey capability, including a Navy survey fleet of no less than eight ships to meet the critical data requirements of the fleet commanders;
- Exploit new technologies for the rapid collection, processing, and dissemination of weather and ocean data; Pursue state-of-the-art large-scale computer capabilities;
- Establish deep water and coastal "natural laboratories" where military and civil, operational and research communities can cooperate in testing new theories and products;
- Maintain the proper balance for ocean research funding between open ocean and coastal; and keep Navy's ocean science and technology investment to at least its current funding level;
- Establish and fund Navy research Chairs in Oceanography at major oceanographic universities in the country.

Program Structure

There are two primary components within Naval Oceanography: science and technology management and the operational oceanography program.

In ocean science and technology, Navy now represents about a quarter of the national investment. Under the Chief of Naval

Research, the Office of Naval Research (ONR) was founded in 1946 to continue the partnership between the scientific community and the Navy that demonstrated great value to the nation in World War II. This year marks ONR's 50th anniversary and it was recently reorganized to manage a fully integrated science and technology program, including a growing cooperation with industry and process manufacturing technology. ONR manages the transition from the long-range vision of fundamental scientific research, through additional development, to testing the feasibility of applications for Naval operations. ONR balances Navy requirements with emerging opportunities offered by the scientific community. ONR's ocean science and technology activities provide a test bed for high risk, innovative approaches that later find their way into Navy systems and operations -- and into civilian applications as well.

ONR ensures access for Navy to the newest science and technology developments and future expertise for the nation. Examples in the area of oceanography include acoustics, coastal oceanography, remote sensing, numerical prediction, marine meteorology, and, most recently, ocean optics.

Navy's operational oceanography program provides critical tactical environmental information -- from the seafloor to the upper atmosphere -- to U.S. military forces throughout the world. Meteorology and oceanography (METOC) together describe and predict the most changeable aspects of the marine environment. U.S. civil agencies concentrate primarily on the U.S. and its territories, but Navy requires timely, accurate forecasts worldwide to support the full spectrum of Fleet operations, wherever and whenever the Fleet operates. Navy large-scale supercomputer models, which analyze and predict changes in both the oceans and atmosphere each day, serve as the basis for military global forecasts and predictions. On-scene support is delivered by forward-deployed Navy oceanographers, who tailor data and products for local use. Some of this data is also inserted directly into command and control systems to support automated "tactical decision aids" for planning and optimizing sensor and weapons employment.

In the area of mapping, charting, and geodesy, the Naval oceanography community works closely with the Defense Mapping Agency (DMA). Navy collects survey data for the nautical charting efforts of DMA throughout the world, and both work together with the National Oceanic and Atmospheric Administration (NOAA) in developing new survey and charting technologies. NOAA surveys U.S. waters and territories out to 200 miles, but overseas hydrographic surveying is Navy's responsibility. Navy's multi-mission survey fleet of eight ships also collects oceanographic and acoustic data to support antisubmarine warfare, mine warfare, amphibious and special operations. Unified and fleet commander requirements for these types of data far exceed the resources available to meet them, so survey vessels must be scheduled based on the highest priorities. With the end of the Cold War, Navy's survey ships are gaining unprecedented access to previously denied coastal regions. Navy data collection is augmented through international agreements with foreign navies whereby the U.S. Navy provides selected expertise and equipment, while much of the data is collected by foreign ships and personnel. In this area too, Navy's oceanographers are negotiating with many nations with which formal cooperation would not have been possible just a few years ago.

Navy's operational oceanography program also includes astrometry -- the positions of celestial bodies -- and precise time. These disciplines are crucial to support precise navigation, satellite operations, surveillance, reconnaissance, missile targeting, and secure global communications. Increased reliance on advanced technology has created a defense requirement for precise time measured to one-billionth of a second! Since military requirements for time accuracy are the most demanding, the U.S. Naval Observatory in Washington DC maintains the nation's Master Clock and disseminates its time signal to all users.

The operational Naval oceanography program includes a total military, civilian, and reserve force of about 3000 people and costs less than one-half of one percent of the Navy's total budget. This investment yields major payoffs by minimizing risk to Navy personnel in ships and aircraft, reducing platform and equipment damage, and delivering weapons accurately on target. It provides a high-tech edge to U.S. forces to help them operate faster, more safely, and more effectively.

Clearly, Navy's operational program requires the strong support of basic and applied research. With the operational shift in focus to the complex littoral zones, the research and operational components of Navy's oceanography effort are working even more closely together to foster development of new and improved sensors and to quickly transition technological advances from research to the operations.

Navy Ocean Partnerships

The idea of partnerships is certainly not new to Navy. The Navy ocean program relies heavily on advances in basic research from academia; other agencies provide backup operational support; and Navy obtains vast quantities of global data from national and international civil oceanography sources. In fact, the overwhelming majority of the METOC data used on a day-to-day basis to support Navy operations is not collected by Navy.

On the other hand, Navy is a major provider of oceanographic information and expertise, as well as a user. Navy makes over 90 percent of its environmental data and products available to the public, either in real-time or through later declassification, and these support a wide range of civil applications. Tax dollars invested in Naval oceanography support the public -- either directly or indirectly -- through development of new materials and technologies, deep sea research, satellite remote sensing, the development of undersea vehicles, overseas nautical charts, typhoon warnings, oceanographic and meteorological data bases, ice forecasts and other prediction models, precise time, and data that support environmental quality studies. Navy also builds ocean research vessels for universities to operate. The last ship in a recent upgrade of the university fleet, the research vessel ATLANTIS (AGOR 25), will be launched next week in Pascagoula, Mississippi and turned over to the Woods Hole Oceanographic Institution for operation.

Many important partnerships are already in place, and there are some real success stories.

A basic and applied research experiment conducted in 1995 at the Army Corps of Engineers Facility in Duck, North Carolina, highlights the importance of dual-use partnerships in coastal ocean research. ONR, through a partnership with the Army Corps of Engineers, the National Science Foundation, U.S. Geological Survey, and a number of other agencies, initiated a project to better characterize the coastal environment using a variety of in-place and remote sensing devices. Results of this experiment, now emerging in scientific journals, will provide a basis for improved techniques in amphibious operations as well as civilian coastal engineering concerns and resource management.

Crucial to Navy's success in coastal regions is development of higher resolution remote sensing techniques as well as autonomous systems with increased on-scene information processing capabilities. ONR is initiating a program to understand the content and utility of a "weather signal tap" from the AEGIS SPY-1D radar system. As this technology matures, the AEGIS system could be configured to accept or reject environmental data internally, reducing clutter and false targets in real-time. Such techniques, once developed, could be used to provide improved support to both military and civilian applications, especially aviation.

Another science and technology partnership is the concept for a network of inexpensive undersea vehicles and components linked by acoustic modems. Initially driven by the need for cost-effective measurements under the Arctic ice, this may prove to be a very efficient means to survey the world oceans for a variety of uses. As a result of this emerging technology the ocean community, at large, will benefit from vast improvements in ocean observations. Potential military applications for this same technology range from mine warfare to antisubmarine operations. Much of this work -- as well as many of Navy's past accomplishments in deep submergence -- are subjects of a pending report of the National Research Council's Marine Board on "Undersea Vehicles and National Needs."

The important role played by the Arctic Ocean in global climate, and international concern for pollution in the region, have fueled greater interest in Arctic research by civilian oceanographers. Navy's submarine community now works with ONR and the National Science Foundation to host an annual Submarine Arctic Science Cruise, called "SCICEX," for researchers aboard operational submarines under the Arctic ice. This program gives unprecedented access to Arctic oceanography for all scientists while providing Navy with an additional mission to maintain proficiency in under ice operations.

Another exciting example of dual-use possibilities involving a Navy operational system is the Integrated Undersea Surveillance System (IUSS). Developed during the Cold War to counter the threat posed by the Soviet submarine fleet, the system is primarily comprised of a set of acoustic arrays on the seafloor known as the SOSUS system. Initial investigations of civil applications, coordinated closely with NOAA, proved remarkably fruitful. A short demonstration project provided more information on marine mammal movements than all the previous data collected in history. SOSUS also proved to be the most effective monitoring system for underwater seismic events, indicating the possibility of better earthquake and tsunami (or "tidal wave") predictions. NOAA even demonstrated the SOSUS system could aid in fisheries enforcement by detecting illegal deployments of fishing nets. Researchers propose to use the system for acoustic monitoring of the ocean itself, since sound travels at different speeds through water depending on density and temperature. To assist the scientific community with their research activities, Navy has established procedures both for allowing cleared scientists access to some parts of the SOSUS system and to the original acoustic data from SOSUS. Mechanisms are also in place to review and tailor the data for public release.

Navy's closest Federal partner in operational meteorology and oceanography has long been NOAA. Navy and NOAA have more than a dozen formal agreements that govern cooperation in a wide range of technology development, modeling research, data processing, and product exchange activities.

For example, Navy's Fleet Numerical Meteorology and Oceanography Center is directly linked to NOAA's National Weather Service for routine exchange of weather and ocean forecast products. Not only do NOAA and Navy share information to improve a variety of dual-use products on a daily basis, but they provide a mutual backup capability should a catastrophe render either center's supercomputer or communications systems inoperative. This keeps the nation's public and commerce moving safely and efficiently while ensuring the military gets the information needed to exploit the environment. Navy also has an oceanographic data distribution system that provides digital METOC products to remotely operating military units. Through an agreement with NOAA, most of the products are transferred in real-time for dissemination to civil users. The public gets information with many commercial and research uses.

The national data centers, operated by NOAA, are relied upon to archive Navy data and disseminate it to the civil community. In addition to serving the needs of the general public, these centers provide Navy with historical data critical for air and ocean modeling in tactical METOC systems. Through this partnership easy access to important data is gained from around the world that might not otherwise be readily available. Navy strongly supports continuation of the government-run national data centers.

In the area of remote sensing, Navy, Air Force, and NOAA have long shared the task of collecting and processing vast quantities of atmospheric and oceanic data from civilian and military satellites. Few civilian oceanographers realize that the sea surface temperature fields used routinely in their research have been processed at the Naval Oceanographic Office. DOD, NOAA, and NASA are now converging the civil and military satellite programs into a single system that satisfies their different requirements and will be considerably less costly to the taxpayer.

The National Ice Center, located in the Washington area, is another good example of military/civil partnerships. Operated cooperatively for nearly 20 years by Navy and NOAA, with Coast Guard joining last year, the Center provides ocean and Great Lakes ice analyses and forecasts for Navy and civil users around the world.

A unique collaboration between Navy and the national Geographic Society is the "MARCO POLO" educational program. Each year selected students and teachers board Navy survey ships for about two weeks to learn the basics of at-sea navigation and ocean data collection, as well as study the history and geography of the areas they visit.

Public access to Navy information has been an active and important issue in the Naval oceanography community over the past decade. In response to enormous changes in the world's political/military situation, major changes have been made in classification, foreign disclosure, and export control policies. In partnership with the Congress, Navy participated in then-Senator Gore's working group that reviewed the usefulness to global modeling research of the Arctic under ice data collected by Navy submarines, and the feasibility of declassifying it. As a result Navy was able to make much of the data available to researchers.

In a follow-on bipartisan initiative, Senator Gore and Director of Central Intelligence Gates established an Environmental Task Force (ETF) of academic scientists to be cleared for access to very highly classified information, and to review intelligence and defense databases and systems to determine their potential usefulness for addressing serious global environmental problems. The Central Intelligence Agency and Defense Department agreed to the plan, and the Oceanographer's staff has taken the lead for Navy in responding to ETF requests. Some important decisions have been made. Last July Navy completely declassified all Navy altimetry (or ocean height) data collected from the GEOSAT satellite. The research community has already used this comprehensive data set to produce some startling improvements to the nation's knowledge of global ocean and seafloor features and the earth's gravity field. Navy positions on all ETF data declassification and access requests soon will be submitted through Department of Defense to the Vice President.

A follow-on effort to the Environmental Task Force is called MEDEA. This group of academic scientists with security clearances has reviewed and reported on additional issues of data release and access, including a comprehensive look at the full range of the Navy's oceanographic data sets. Ocean research uses of data from the nation's highly classified overhead imagery assets are also a part of this effort.

Naval oceanographers in both the research and operational communities also participate in many interagency ocean policy activities, as well as working with academic groups, such as MEDEA, the National Academy of Sciences, and Admiral Watkin's Consortium for Oceanographic Research and Education (CORE). The Commander of the Naval Meteorology and Oceanography Command, in his testimony, will present some new ideas for expanding oceanography partnerships that have come out of cooperation with these groups.

Conclusion

The number of Committees involved in this hearing reflects the importance the House of Representatives places on oceanography. Navy will provide any assistance the committees may require to facilitate their efforts in this area. Navy is committed to an active partnership with Congress, and other members of the national ocean community, to build coherent, forward-reaching ocean policies and programs for the future that will preserve the United States as a world leader in the field.

In some cases where Navy assets can be of specific use for civilian application -- such as continued operation of some parts of the SOSUS system no longer needed for Navy use, or costly adaptation of classified data sets for public release -- there are unresolved funding issues. Navy supports as much public access to Navy data and systems as is feasible, and looks forward to working with Congress in addressing the policy, organization, and funding issues necessary to realize these opportunities.

Mr. WELDON. Thank you, Admiral Boorda, for your statement. Admiral Gaffney?

STATEMENT OF REAR ADMIRAL PAUL G. GAFFNEY, II, USN COMMANDER, NAVAL METEOROLOGICAL AND OCEANOGRAPHIC COMMAND, STENNIS SPACE CENTER, MISSISSIPPI

Admiral GAFFNEY. Distinguished chairmen and members, good morning.

It is an honor to appear before you, to join the distinguished panel you have assembled, and to know that the future of the national oceanographic capability has such strong interest.

I too have prepared a testimony which I have submitted for the record, and if you agree, I propose to take just a few minutes to punctuate a few of its points.

First, so you know who I am, I am charged with execution of the operational half of the Navy's Oceanography Program. My job is to continually, and in real time, characterize and predict the maritime battlespace.

We collect data globally. We process it into useful information and distribute it in many forms to Navy and other operating forces.

Our effort is global and our people are all over the world today, almost any place you can imagine. But my headquarters, happily, is on the gulf coast of Mississippi, just two miles from the Louisiana border and I'm smack dab in the middle of Congressman Gene Taylor's district, and I'm really pleased that he's here today to support us.

You have heard, or you will hear, a great deal about ocean research and development today. I don't conduct or manage any. But I use more of its successes than probably anyone else you'll hear from. So I am probably the strongest proponent of Navy- and other agency-sponsored ocean science than anyone you have met.

I exist not because the Navy has a keen interest in oceanography for oceanography's sake. Or because we have a federal charter in oceanography. I exist, rather, because the Navy has made the decision that it requires comprehensive oceanographic information to be able to operate safely and effectively wherever it needs to on this planet.

That Navy decision, reaffirmed each budget cycle, has accumulated for us, and for the nation, a substantial capability.

Over the past year and a half or so, I have taken a strong position on partnership opportunities and their value for three interrelated reasons.

The first, we in the Navy face complex technical challenges each day. Today, that challenge is to quickly gain skill in characterizing the littoral environment, without losing the deep ocean capabilities that took us 50 years to accomplish.

We need new ideas as we shift from scales of hundreds of miles and days to scales of tens of meters and minutes. Partnering with scientists from industry, academia and other agencies who have related challenges, but may look at them from other viewpoints, will help me address the micro-scale oceanography that affects naval expeditionary warfare.

In a sense, partnering helps me ensure that naval oceanography has peripheral vision.

Second, I personally believe that the Navy has an obligation to the general well-being of this maritime nation, to make its substantial oceanography capability available to pursue other national goals when it is affordable and does not unduly risk national defense.

And finally, we do exciting things. We have unique tools, talents, and resources in the Navy. And we face oceanography's most interesting challenges.

I believe that if we interest young researchers and even students in our operational problems, we will ensure that there's a cadre of technical talent on whom the Navy can call for decades. Partnering can surely contribute to that goal.

You have heard reference to MEDEA today and your committees have copies of MEDEA's recent ocean panel report. For review, MEDEA is a collection of the nation's very best scientists principally from industry and academia, all cleared to the highest security levels.

I asked MEDEA to review my data holdings and processes, first and foremost, for quality. And secondly, for the potential utility it might have in meeting nondefense goals. And I wanted their ideas on how to strengthen the historic bond between Navy oceanographers and their civil counterparts.

MEDEA delivered in all three areas. Our capabilities as judged by them are world-leading. Several data sets were highlighted for potential release in whole or in part and they articulated several partnering notions to link operational Navy oceanographers and civil researchers.

They included natural laboratories in the United States littoral waters, electronic data access directly into the Navy, Navy archival of national technical means imagery of the oceans, use of at-sea assets better, and people-to- people exchanges.

MEDEA also helped the Navy spur on its efforts at unclassified oceanographic cooperation with the Russian navy recently.

Continuation of the substantive involvement of the CIA-sponsored MEDEA ocean panel will ensure enlightened and understanding dialogue on declassification, while providing increased peripheral vision within the classified parts of my program.

Timing is everything. Just as the bipartisan-spawned MEDEA-ETF initiative was blossoming, Admiral Watkins at CORE began a grassroots partnering effort with industry and academia, and he took time early in that effort to include operational oceanographers in his visionary plan.

And the Chief of Naval Operations reviewed naval oceanography, as he just told you, declared it a core capability and core responsibility of the Navy, and he charged us to assume a role of national leadership in oceanography.

And now, your three committees have made a commitment unprecedented for decades, more than 25 years, to bring this national capability together.

Let me conclude by saying, from Navy Oceanography's viewpoint, there are many opportunities. We are talking like partners today more than ever. And we have a Navy leader in the CNO—we call him the Chief of Naval Oceanography, Admiral Boorda—who has embraced oceanography partnering.

Predictably, there are some small fiscal challenges and some new security challenges. And, obviously, not every opportunity that we can come up with to leverage will be realized.

But, thanks to your great support, many, many will.

Thank you, Mr. Chairman.

[The prepared statement of Admiral Gaffney follows:]

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HOUSE OF REPRESENTATIVES

STATEMENT OF

REAR ADMIRAL PAUL G. GAFFNEY, II, U. S. NAVY

COMMANDER, NAVAL METEOROLOGY AND OCEANOGRAPHY COMMAND
STENNIS SPACE CENTER, MISSISSIPPI

BEFORE THE

SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT
OF THE HOUSE COMMITTEE ON NATIONAL SECURITY,

THE SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS
OF THE HOUSE COMMITTEE ON RESOURCES,

AND THE SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
OF THE HOUSE COMMITTEE ON SCIENCE

ON

LEVERAGING NATIONAL OCEANOGRAPHIC CAPABILITIES

JANUARY 25, 1996

NOT FOR PUBLICATION UNTIL RELEASED BY
THE COMMITTEE ON NATIONAL SECURITY
HOUSE OF REPRESENTATIVES

Navy Focus -- National Impact

Good Morning Chairmen, I am Rear Admiral Paul G. Gaffney, II, USN, Commander of the Naval Meteorology and Oceanography Command, with headquarters located at the Stennis Space Center, MS. Thank you for the opportunity to testify for the Navy on this important concept of Federal-National collaboration in Oceanography.

As an island Nation, protected from aggressors and linked to partners by the world's great oceans, it is fundamental that we understand the marine environment around us. It is equally fundamental that a Navy, especially a global Navy, understand the medium in which it must train and operate. In fact, the maritime environment is the root discriminator that separates navies from armies and air forces. It follows then that navies require, as a matter leading to successful mission execution, the very best knowledge of oceanography and its allied sciences.

Several agencies have been assigned duties which include furthering oceanic knowledge for the national good; each has important competencies. But, no agency requires oceanographic information to carry out its basic mission more than the United States Navy. That statement is not meant to lessen the importance of the other agencies, the high regard we hold for them or our dependence on them. It is meant to punctuate the basic and undeniable need the Navy has to understand the ocean to ensure its national defense operations are executed safely and effectively. So when the Chief of Naval Operations tells us he wants the Navy to be a National leader in oceanography and that **oceanography is a core requirement and responsibility of the Navy,** it's not because he wants another mission or because he finds oceanography interesting, it is because we must have a top rate global oceanographic program focused on supporting Navy missions.

For decades the Navy has recognized that in developing that kind of capability, it has also accumulated talent, tools, information, and resources that can help contribute to other National ocean goals. Senior Navy leaders have understood their responsibility to apply such capabilities to other National goals when it does not risk, but rather, enhances, national defense.

Others have recognized Navy oceanography capability too, and the two-way value of Navy-civil partnerships in oceanography. A group of enlightened ocean scientists from industry, academia and Government came together in 1994, under the name MEDEA, to explore mutual oceanographic leveraging. Many of the concepts developed later in this testimony were first discussed with MEDEA and others, like their allies at the Consortium on Oceanographic Research and Education (CORE). The initiative of your committees is particularly opportune because you can take advantage of their momentum to achieve your goal of greater cooperation in an area critical to this maritime nation.

By way of introduction let me explain that the Navy's comprehensive oceanography program has two principal components of interest to this hearing: Ocean Science and Technology and Operational Oceanography.

My command, under the Chief of Naval Operations, is charged with the operational execution of Naval Oceanography. It is the world's preeminent organization for the global collection, assimilation and archiving of ocean data; analyses of these data and subsequent modeling and prediction of oceanographic, meteorological, bathymetric, acoustic and other geophysical phenomena; the generation of information useful to Navy and Marine Corps forces and other DoD Services operating from or near the sea; and the delivery of relevant maritime environmental information to and provision of face-to-face operational advice to Naval and other DoD forces.

A few metrics: we operate a fleet of ocean survey vessels permanently deployed overseas. Today, we are nearing completion of a recapitalization effort that will deploy eight vessels by the end of the next fiscal year; most are new construction. We operate two world-class supercomputer centers which manage and model ocean and atmospheric information for the Navy and DoD. And, most importantly we maintain a cadre of approximately 3000 military and civilian oceanographers, meteorologists and technicians around the world supporting the operations of the Navy and Marine Corps and Joint forces in many arenas. At once we maintain critical capabilities in operational centers and we are collocated with warfighting forces at sea and forward ashore. By any set of metrics, the Navy has developed a leading capability.

Our efforts are comprehensive and include:

1) conduct of ocean survey on a global basis using ships, aircraft, satellites, ROVs, buoys and a worldwide set of international agreements;

2) global numerical weather and oceanographic analysis, modeling and prediction;

3) first rate management of extensive and high quality data bases on the maritime environment (ocean, air, ice, and ocean bottom); and

4) operation of state-of-the-art, high performance computational devices to manage such vast quantities of data and produce useful information therefrom.

While not as comprehensive as we would like it to be, Naval Oceanography presents a substantive capability that comes from decades of steady modest Navy (and DoD) investment. Like every other part of the Navy, we do and we will aggressively pursue the resources necessary to accomplish our mission. We seek to retain our talent base (both military and civilian), modernize our survey capability, capitalize on international partnerships, and keep up with the explosive developments in computation and communications/networking. We are not specifically funded to help other, non-Defense agencies complete their ocean-related functions. Yet, we understand that we own and operate certain capabilities that can help others -- and we look for opportunities to make them available when it does not interfere with our primary mission or adversely impact our financial or security position. Likewise, we will embrace proposals from other entities who wish to leverage their investments by partnering with us.

There is little doubt that the Navy's cumulative investment in oceanography provides for a strong position in the National oceanographic leadership. Yet, I am not satisfied that we have done as much as we can to support the oceanographic needs of our Naval and DoD forces -- my first priority. Two areas are worthy of mention as examples:

o We need greater understanding of the ocean's fundamental processes. For decades we focused on understanding, describing and predicting the few, rather large and conservative features of the deep ocean that affected acoustic transmission and, therefore, submarine detection. Today, we must still concern ourselves with that problem and ensure our deep water skill is not lost. But, we now face additional and more complex challenges in trying to understand the critical processes in the littoral ocean environment. The littoral varies on the scales of meters and minutes. We have all seen the broad expanse of warfare that can occur in the littoral zone: ASW, amphibious operations, special operations, mine warfare, and, of course, safe navigation in shallow waters. So, it is vital that we are able to characterize and predict the environment there and its effect on each warfare operation and system. R&D investment in the shallow and coastal waters of the littoral, in the past relegated to a lower-tier priority, is critical today.

o We always need data, all kinds of oceanographic data from ocean depths, to temperature, to currents, to information about marine life, to local air-sea interaction phenomena. Navy has a great wealth of information in its classified and unclassified holdings. Using deliberate review methods we are trying to increase civil access to our data. Partnering with our civil counterparts is a two-way street, though. Just as the civil scientist covets access to Navy's vast data holdings, the Navy seeks continual and rapid access to the sets of quality data collected by all American scientists.

The Office of Naval Research (ONR) and its renown corporate lab, the Naval Research Laboratory (NRL), execute the other important part of the Navy's program: **the Navy Ocean Science and Technology Program.** It's history is rich in accomplishment, and its demonstrated willingness to work with other agencies to gain basic knowledge is a model. Oceanography is among the most naval-relevant of all fields of research. It only stands to reason that it has been designated a core competency by the Chief of Naval Research. It is ONR's famous ability to find and invest in the best research (in and out of Government) that makes it so important. ONR's insistence on quality and on understanding the basic processes of the ocean give me the knowledge to decide which data to collect, how to collect and process it, and the ability to connect that knowledge in a useful way to fleet requirements and operations. ONR's traditional, strong and stable investment in ocean science and technology is critical to me and to our National capability in oceanography.

You asked me to testify on how operational oceanography capabilities are linked to civil needs and capabilities, and vice versa; a complement to ONR's strong, traditional linkage to academia and industry. It is that concept, and a philosophy of exposing one's challenges to a wide variety of bright people, that led me to call upon MEDEA. MEDEA, a group of the Nation's very best scientists -- principally, from industry and academia -- cleared for access to classified information, grew out the then-CIA Director Gates and then-Senator Gore's bipartisan initiative to find collateral uses for national reconnaissance information, especially those which could contribute to solution of general environmental problems. I wanted to expose the MEDEA scientists to our capabilities and, conversely, to expose our operational oceanographers to other bright people in the same field; ensure peripheral vision, if you will.

I asked the Ocean Panel of MEDEA to review Naval oceanographic, meteorological and ice data holdings for several reasons. First, it was a method to reinforce the connection between Navy's operational oceanographers and the Nation's best civil ocean researchers. Second, it was a chance, for the first time, to get cleared scientists from outside of the Navy to review and judge the quality of our work. Third, it allowed the Panel to judge the utility of the Navy data for other National purposes. The result of their work was published in an unclassified report called: "Scientific Utility of Naval Environmental Data," June 1995. Copies have been made available to your committees for their use in your partnership initiative.

The Report was highly acclaimed outside of the Navy and is substantially useful inside. Not only was the quality and extent of Navy's ocean data holdings strongly endorsed, and its utility described, but a number of other initiatives were articulated that aimed at reinvigorating and maintaining a close linkage between operational Navy Oceanographers and those renown scientists doing research on Navy and other National ocean topics.

As MEDEA was finalizing its results, the Navy, internally and independently, under Admiral Boorda's personal and direct leadership, was reviewing its oceanographic program. In that review, called a CNO Executive Board (CEB), he covered both Ocean Science and Technology and Operational Oceanography and supported development of a policy statement (since issued) aimed at ensuring oceanography was indeed a core requirement and responsibility of the Navy. Central to his decisions is the importance of Navy leadership in the National oceanographic scene. Admiral Boorda has reviewed that for you already.

Clearly both the Defense and the civil sides of oceanography have strengths and needs, including those whose talents and assets give them a claim to leadership. In any case, if one is to be a National leader, as Admiral Boorda directs, there are certain responsibilities one has. There are also benefits that accrue to leaders who are actively engaged with others in true partnerships. From the Navy Oceanography viewpoint there are several opportunities which might be leveraged by others to enhance our National capability.

First, I am chartered to ensure that the Navy and DoD have the very best oceanographic support possible within the funding available. To do otherwise, even for other lofty goals, is contrary to the program dictates which are implicit in current authorizations and appropriations. I take seriously the CNO's policy statement about oceanography's core status. I will fully fund and deploy as soon as practical a fleet of no less than eight survey vessels, maintain a state of the art computational capability to archive and analyze data and predict ocean and atmospheric conditions for the DoD. I will seek to use all-source satellite data to best describe the ocean. I will retain a stable, competent workforce of officers, civilians and enlisted personnel as stewards of Navy's core oceanographic competency. At the same time, I should also make smart investments in improving my capability by harnessing the brainpower of the National scientific body.

Second, the Navy has committed to stable, long term science and technology investment in oceanography with a rather balanced apportionment of funds between shallow and deep water process studies. As the end user for most science and technology successes, I will continue to argue for priority funding for the ocean sciences within the Navy.

Third, partnerships between Navy Operational Oceanographers and the civil sector are not new. Today, the Navy operates the National Ice Center with the Coast Guard and NOAA. The Naval Oceanographic Office operates a Major Shared Resource Center which provides supercomputer capabilities to operational ocean modelers and over 2000 Defense-supported civil and Government researchers who need large scale computers for geophysical and other fluid dynamics calculations. We work with other agencies and governments to maintain a suite of buoys in the high Arctic which relay environmental information. NOAA, Navy and Air Force share responsibility, using their respective Centers of Expertise, for analysis of ocean and weather data sensed from space (the Navy operates Centers of Expertise in Multi-channel Sea Surface Temperature analysis, Special Sensor Microwave Imagery of the ocean surface, and satellite altimetry data fusion). Academia, American commerce and other Government agencies all benefit from such cooperation. These are just a few examples.

Next, The Navy has unclassified and classified data holdings that are among the world's most extensive. It is of the highest quality and it is managed in a technically up-to-date manner -- easily reached and inter-related. These data sets have been judged to have utility in civil ocean research. The Navy has committed to quick, but deliberate, review of these data for potential declassification and release. When full declassification is not possible, I will work with cleared members of the scientific community over the long term to find ways to make available segregated blocks of data, decimated data or useful products derived from the classified data. One will note that as an outgrowth of the CNO's Executive Board on Oceanography, Admiral Boorda decided to release previously classified GEOSAT altimetry data which are now being used by academics and NOAA scientists to predict deep ocean topography.

MEDEA praised the Navy's management of oceanographic data as first rate. Navy's data base management systems are being upgraded to allow for ease of data access and the interrelationship of various data types, all electronically. They have suggested that electronic access to unclassified Navy data and model information using current networking technologies would aid students and researchers with valuable information. Such paths can inspire and allow two-way exchanges of data. While the MEDEA suggestion is technically feasible, it is not funded in a full blown sense. We do have rather new "internet" homepages that allow electronic access to information about some of our data and numerical products. This is fertile ground to till. NOAA is advancing here, as well. Consultation with NOAA and other potential users of the data we collect and manage is increasingly important.

One proposal that comes out of the MEDEA deliberations is that the Naval Oceanographic Office become a repository of very highly classified data collected by National Technical Means (NTM) at specified geolocations in the ocean, called "ocean fiducial sites." At these sites the Navy and cleared civil scientists would be able to observe the ocean over long time periods by comparing the comprehensive unclassified and classified data holdings already in the Navy's hands with national sensor (NTM) observations. One could make work stations available in the Naval Oceanographic Office for cleared scientists to view and work with all of these data. If Navy becomes a fiducial archive site under CIA Environmental Program sponsorship, I hope to create, within my budget authority, that modest capability for cleared scientists. The return for that investment will be real-time dialogue between researchers and operational oceanographers on techniques for use of remotely sensed data (and other classified geophysical information). The second benefit is greater understanding of Navy operational oceanography problems by those whose research is funded by the Office of Naval Research and others. A more expensive and presently unbudgeted option would be to electronically connect via classified networks to secure facilities already established around the country.

No agency has enough sea going assets to adequately collect the amount of data required for operations or research. Therefore, when these precious assets go to sea they must be as efficient as possible. Greater collaboration among the agencies that own and fund oceanography's at-sea facilities seems a worthy goal. Certainly, classified operations and Law of the Sea considerations preclude centralized scheduling of the military survey and civil research platforms, but partnerships can be reached. For example, a Navy survey vessel transiting from Hawaii to Guam could simply drop a vertical acoustic array being used by Scripps' scientists who are pursuing National Science Foundation research. Military surveyors would not be doing any research, merely dropping off a piece of "research freight" at sea, on a not-to-interfere basis, en route to survey duties. A University of Washington-operated ship could collect gravity data for Navy use incidental to its own research in the Gulf of Alaska. It is possible, that a Woods Hole engineer has developed a way to deploy deep moored instruments that is safer and faster. A Navy surveyor may have found a better way to tow an acoustic transmitter. A commercial seismic engineer may have a better technique for streaming complex receiver arrays. A structured ship visitor/consultant program can help each group more efficiently conduct their time at sea. There are some costs here, but they are not large.

Earlier, I discussed a contemporary Navy challenge: understanding the littoral. One response which could leverage Navy and civil capabilities and be cost efficient would be to establish natural laboratories in US waters (the Gulf of Mexico, Gulf of Alaska, Buzzards Bay, for example) to serve as surrogate environments for those classes of the littoral to which the Navy cannot get ready access overseas. Harnessing the talent of local oceanographic institutes (in the Gulf of Mexico, for example, one might consider: U of Miami, Florida State, U of Southern Mississippi, Mississippi State, LSU, University of New Orleans, Tulane, Texas A&M, ARL Texas, Naval Research Lab Detachment Mississippi) who have been watching their back yards for years. One would add Navy operational data sets and modeling capabilities. Data collection and on scene research would use various university ships in the area, thereby saving steaming funds. Such an effort addresses a critical Navy need, but also can help EPA, Minerals Management Service, Corps of Engineers, State Fisheries, Environmental and Marine Science agencies and others as well. The Office of Naval Research is investigating variations of this theme as a result of the CNO's Executive Board on oceanography. I am eager to join this effort with my in-kind capabilities.

Before I leave the challenges of the littoral, let me punctuate the value of partnering with top oceanographers outside of the Navy; I called it peripheral vision earlier. Just this month, the MEDEA Ocean Panel met with scientists from the Naval Research Lab, the Naval Oceanographic Office and with me in Mississippi. The MEDEA concept, with its cleared membership substantively involved in relevant experiments, represents a partnership with ongoing success. It allows one to focus national talents on high priority, new and complex challenges using the best national assets. The MEDEA Ocean Panel has, in my opinion, become wedded to the micro-scale littoral challenge that the Navy faces because it is intriguing, important and new tools are available. Navy oceanographers have been able to capture new thoughts, ideas for further research and some rules of thumb that operational Naval oceanographers can use from this partnership. I would recommend continuation of a substantive MEDEA effort under any new partnership initiative; because I have seen it work already.

For several decades now, the Navy has sent a few oceanography-specialist officers to graduate education at civilian schools for oceanography. For example, I went to Catholic University here in Washington, my Executive Assistant went to Scripps, one of my Commanding Officers to Florida State, my predecessor went to the University of Washington. The large majority go to a very rigorous, specially tailored double-masters degree program at the Naval Postgraduate School in Monterey. Monterey's rigorous, high quality program is the best prescription to meet our general needs. But, I trust we can continue to afford the opportunity for a few students each year to achieve graduate degrees at other prestigious universities. It does provide the Navy with a few different viewpoints on technical issues, and it develops lifelong ties to civilian experts in academia upon whom we must call. It is a method to ensure a degree of peripheral vision for the Navy and gives academia visibility, however informal, into Navy oceanography. This is a program I hope to continue to encourage when the right matches can be made.

There are many great ideas being pursued in the oceanography centers in this Country. It is important to me that both the Navy's ocean scientists and our operational oceanographers have access to them. Likewise, it is important that students and civil researchers be exposed to Navy's oceanography challenges and be excited by them, so that we might draw on them for relevant solutions to our problems throughout their research lives.

As a national leader in oceanography, the Navy recognizes its responsibility to the country. To the extent that security is safeguarded and funding is available and appropriate, Navy's operational oceanography enterprise will continue to pursue National leveraging opportunities as it focuses, absolutely, on better support to the operating forces .

RADM PAUL G. GAFFNEY, II

UNITED STATES NAVY

COMMANDER, NAVAL METEOROLOGY
AND OCEANOGRAPHY COMMAND

Rear Admiral Gaffney assumed command of the Naval Meteorology and Oceanography Command on August 15, 1994. He was most recently the Commanding Officer of the Naval Research Laboratory in Washington, DC, with major offices in Mississippi, Florida and California from 1991 to 1994. During the period 1989-91, he was the Assistant Chief of Naval Research in the Office of Naval Research, Arlington, VA. Previously, he was the Director of the Oceanography Resources Division in the Office of the Chief of Naval Operations from 1986-89.

A 1968 graduate of the U.S. Naval Academy, he was selected for immediate graduate education and attended the Catholic University of America in Washington, DC, as a student and research associate during 1968-69. He received a master's degree in Ocean Engineering. He served from 1969-71 as Operations Officer on board USS WHIPPOORWILL (MSC 207), a minesweeper homeported in Sasebo, Japan.

In 1971, he commenced a series of oceanography assignments, beginning with duty as the Commander, U.S. Naval Forces Vietnam Staff Oceanographer and Advisor, Vietnamese Navy Combat Hydrographic Survey Team. In 1972, he was assigned as the Oceanographic Services Officer at the U.S. Fleet Weather Central in Rota, Spain. He returned to Washington to serve as the Executive Assistant and Aide to the Oceanographer of the Navy from 1975-78.

After a year as a student and Advanced Research Fellow at the Naval War College, Newport, RI, from which he graduated with highest distinction, he assumed command of Oceanographic Unit FOUR embarked in USNS CHAUVENET (T-AGS 29) permanently deployed conducting hydrographic surveys of the Makassar Strait in the Republic of Indonesia, 1979-80.

Next was an assignment as the Director (acting) of Arctic and Earth Sciences Research in the Office of Naval Research in 1980, after which he was selected to be the Military Assistant to the Assistant Secretary of Defense (International Security Affairs) from 1981-83. He then reported to Jacksonville, FL, as Executive Officer, then Commanding Officer, of the Naval Oceanography Command Facility and Staff Oceanographer to Commander, Sea-based ASW Wings Atlantic. While in Jacksonville, he completed a master's degree in Business Administration from Jacksonville University.

Rear Admiral Gaffney's career has been recognized by the following awards: Defense Superior Service Medal, Legion of Merit (3 awards), Bronze Star with "V", Meritorious Service Medal and the J. William Middendorf Prize for Strategic Research at the Naval War College in 1979. He is a member of the Explorer's Club and Sigma Xi.

He is married to the former Linda L. Myers of Ruidoso, NM. The Gaffneys have one daughter, Crista, a student at the University of South Carolina.

Mr. WELDON. Thank you, Admiral Gaffney.

Dr. Frosch?

STATEMENT OF DR. ROBERT A. FROSCH, CENTER FOR SCIENCE AND INTERNATIONAL AFFAIRS, JOHN F. KENNEDY SCHOOL, HARVARD UNIVERSITY

Dr. FROSCH. Thank you, chairmen, and members of the committees.

I think I am here today because I have had a rather curious personal career, in the course of which I have looked at ocean and research and development and technology issues from an unusually large variety of angles, as a research scientist engaged in Navy-related, but rather fundamental, research and technology, as assistant secretary of the Navy for research and development, as assistant executive director of the UN environment program, as administrator of NASA, and for 11 years as the vice president of General Motors in charge of research laboratories, I have seen this kind of thing from a variety of angles.

And though I appear today as an individual, I'd like to say a few things that come to me because I have seen it from so many angles.

As others have said quite eloquently this morning, the planet is dominated by its oceans and an ability to understand how they operate to develop technology to work in and with them, and to apply both the understanding and the technology, is of importance clearly for national security purposes, for economic purposes, and for the way in which we live around the edge of the oceans.

Nearly half our states are salt water states and most of our people actually live close to the ocean, and large parts of our economics and commerce are connected with the oceans.

The oceans are important in our understanding of climate and in the generation of climate and weather.

So understanding them and knowing how to use them and work in them can be a major asset to U.S. living from all points of view.

We frequently hear the term, dual-use technology. Is there dual-use technology? Can technology be used for more than one purpose?

My view, after looking at it for a long time, is that I don't know of any single-use knowledge or single-use technology. It always seems to be the case that knowledge and technology, if it is deep knowledge and fundamental understanding of how to do things, is usable for all the purposes that interest us. And you have certainly heard some examples this morning of the use of knowledge and technology developed for naval purposes, for civil purposes, and the same is true in the other direction.

While there is plenty of cooperation among agencies and between agencies and academia, perhaps the weakest part of cooperation over the years has been the link between current and potential ocean businesses and the well-coordinated or relatively well-coordinated attempts to link ocean-related federal agencies and academic institutions.

The Sea Grant Program has over the years done a good deal to try to link what we learn about the oceans with businesses that might use it. But there are difficulties in doing so which we will need to think about.

While there are some large firms and large aggregations of firms in businesses related to the ocean—oil and gas and parts of shipping—a large number of the ocean-related businesses and businesses that operate on and near the seacoast, consist of numbers of small- and medium-sized firms with relatively little individual capacity to do research and development, and sometimes relatively little capacity to know how to benefit from the available knowledge.

For example, many parts of the boating and recreational industries, the construction industry when it works on homes and even on businesses near and on the coast, and even our communities which share common problems with sewage, flooding, water and coastal construction and beaches when they operate separately and independently, may not individually have the capability to learn what is needed to be learned and to apply it.

At the same time, the individual communities and businesses have that, the federal agencies, for the reasons discussed this morning, are developing such knowledge and technology and trying to share it with all of the other actors in the economic system.

This suggests that we need some further elaboration of mechanisms and institutions that will enable cooperation between the federal agencies, the academic institutions, and the businesses and individual communities and localities that might benefit each other by using and applying what is learned, and by posing problems to those who are doing the research.

Though I'm not sure what kinds of institutions are required, but I'd like to make a couple of comments about some characteristics that they must share.

While high-level commissions and coordinating bodies and organizations are useful, the lifeblood of knowing how to use knowledge and knowing what the problems really are is direct contact between those who are doing the research and development and generating the knowledge, and those in communities and businesses who might benefit by it and who might ask important questions that will lead to new and important and useful research.

Arms'-length mechanisms of the kind beloved by our procurement systems are not a very good way to produce informal conversations.

So one of the things I would hope that these committees will do is make clear that the agencies and those who generate the knowledge are authorized and encouraged to talk and to develop networks of informal contact and coordination across all levels of government and with the businesses and industries that will use the results of the knowledge and technology that are generated.

I make the point because we sometimes have formal statutory and regulatory mechanisms that stand in the way of such conversations—not always, but sometimes.

There have been applications of the Federal Advisory Committee Act which have been made difficulties and there are aspects of procurement that make difficulties.

Without arguing that there is no necessity for vigilance and concern over bias and conflict of interest, I think it is important that there get to be mechanisms by which informal conversations about ideas can continue and be encouraged.

And one final and perhaps bold comment.

I'm particularly glad to see this as a joint hearing. As others have referred to, in the past, it has frequently been difficult to organize and to coordinate things in subjects as diverse as the oceans because the agencies and activities have been spread over so many congressional committees.

I have occasionally had the feeling that one of the tasks of an agency head or a senior official with such a responsibility is to somehow find a way to coordinate committees of Congress. And I'm delighted to see the Congress worrying about how it can present a coordinated and useful set of policies that will view the oceans as a problem which goes across a number of constituencies and a number of agencies.

And that cooperation is likely to be helpful to all aspects of the Federal Government and to all levels of government and business in creating the body of knowledge and technology and using it for our total national benefit.

I think this is a wonderful opportunity and a wonderful initiative, and I thank you for the opportunity to testify on it.

Thank you, Mr. Chairman

[The prepared statement of Dr. Frosch follows:]

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Subcommittee on Military Research and Development
of the House National Security Committee
Subcommittee on Energy and Environment
of the House Committee on Science
Subcommittee on Fisheries, Wildlife and Oceans
of the House Committee on Resources

Joint Hearing on:
Leveraging National Oceanographic Capabilities
January 25, 1996

Testimony of Robert A. Frosch
Senior Research Fellow and Adjunct Lecturer
Center for Science and International Affairs
John F. Kennedy School of Government
Harvard University

Mr. Chairman, Members of the Committee, my name is Robert A. Frosch, and I am honored to testify before you today on the topic: Leveraging National Oceanographic Capabilities.

I began my professional career in 1951 as a research scientist, and later Director, of Hudson Laboratories, created and operated by Columbia University at the request of the Navy, to study the oceanographic factors that influenced the long range propagation of sound in the oceans. The purpose of this research was to build a foundation of knowledge, and to find out how to exploit the knowledge to make possible long range detection of submarines. From 1966 through 1972 I was Assistant Secretary of the Navy for Research and Development. I have also been Assistant Executive Director of the United Nations Environment Programme (UNEP), and Administrator of the National Aeronautics and Space Administration (NASA). I came to the Kennedy School when I retired from General Motors Corporation after eleven years as Vice Pesident in charge of Research Laboratories and later the Research and Development Center. I am currently a Trustee of the Woods Hole Oceanographic Institution.

I appear today as a witness purely as an individual, representing no organization. In my brief remarks I want only to make several simple points, without going deeply into detail.

This planet is dominated by its oceans, which cover some 70% of its surface, play a major role in controlling its climate and weather, and mold and influence its shorelines. In the United States, twenty four of our states border on salt water, more than half our population lives on the 10% of our land which is coastal, a large fraction of our jobs are in coastal areas, and a third of our Gross National Product (GNP) is linked to the coastal zone through fishing, transportation, recreation, and similar activities. The country can be seen as linked to, or divided from, most of the rest of the world by the oceans; they have been both the route of most of our commerce, and a major national security asset. The facts mean that the oceans are important to our national life.

Increasing knowledge of oceanographic events in the tropical Pacific ocean (El Nino, Southern Ocean: ENSO) is enabling us to begin to have a capability to predict some aspects of our climate andweather well in advance. This capability is important for agriculture in the whole country, and for everything else weather affects. Knowledge of the oceans, the ability to measure and monitor them, and the technology to use the oceans, is key to naval capabilities to protect, or to project power; to operate to our best advantage on, above and below the seas. The same knowledge of the oceans, and the same basic technology for using it is also key to preservation and strengthening of fisheries, to aquaculture, to the siting and design of sewage treatment and outfalls, to the location of marinas, to the quality of boating, and to safety at sea.

Understanding the oceans can be a major asset to economic and other aspects of U.S. living. We can take advantage of knowledge of the oceans and the coastal zone to understand how our activities and businesses can be conducted in an appropriate way that uses the properties of the oceans, and the interaction of the oceans with the coast and the coastal zone, to our best short and long term advantage. Knowledge, and technology (seen as knowledge of 'how to' do things), are a foundation for better and more successful businesses, and for states and local communities to use the oceans and coastal zone as assets.

The bodies of fundamental knowledge, and the basic technologies for using the knowledge, required for defense purposes and for civilian purposes are largely the same; they strongly overlap. The knowledge and technology are automatically dual use, although the details of application and the specific embodiments of the technology may differ. I have seldom, if ever, seen a case in which knowledge and technology developed for naval purposes was not usable, and valuable, for civil and business purposes, and vice versa. Naval purposes and civil purposes may emphasize different application problems, may approach them in different ways, and may produce somewhat different areas of knowledge and technology, but the resulting knowledge and technology are usable for each other's purposes. Important developments for the Navy have come from civilian projects, and for civil purposes from naval projects. Having both approaches to somewhat different purposes and problems produces results that are better for both than either would be for each alone.

For this reason, the Navy and other federal agencies heavily involved in the oceans and oceanographic matters, including the

Coast Guard, the National Science Foundation (NSF), the National Oceanic and Atmospheric Agency (NOAA), and the National Aeronautics and Space Administration (NASA) have all, over the years, worked together with each other, and with the nation's academic oceanographic institutions, and with businesses working in, around and with the oceans. The federal agencies have played an important role in creating a national ocean community, both by financial support for the creation of knowledge and technology needed by government agencies to carry out their missions, but useful for other purposes, and by being important agents in bringing members and potential members of the ocean community together.

Perhaps the weakest part today is the link between current and potential ocean related businesses, and the already relatively well coordinated community of ocean related federal agencies and academic institutions. While the Sea Grant program has gone a long way to linking the academic institutions and the federal agencies to states and localities, those links, too, could benefit by further strengthening.

Linking ocean related businesses more strongly with the existing ocean community (and many links already exist) is made more difficult by the fact that, while many aspects of ocean business involve large firms with a capability to generate their own knowledge (eg oil and gas, parts of shipping),and to use it, many ocean related businesses, such as both commercial and sport fishing, boating and recreation, tourism, near shore construction, and beach activities, are made up of a large number of small and medium size businesses. Neither these businesses, or the many coastal communities with common problems with beach erosion, coastal construction,sewage and waste disposal, inshore and near shore pollution and other environmental problems, etc. have the individual capacity to do the research and development required to provide the fundamental knowledge and technology that they need and from which they would benefit. The scale of the required R&D is too large for them. Indeed, it is sometimes difficult for them to find the capacity to learn what knowledge and technology is available, and to use it.

At the same time, the federal agencies, for the reasons given above, are customers for such knowledge and technology, and have the capability and responsibility for its generation. The states and Federal agencies, and academic institutions and private businesses, can all benefit from the development of fundamental knowledge and technology, and from what is learned when applications are made. We have an opportunity to develop further a mutually supporting network of institutions at various levels and in several sectors.

The pattern of needs and responsibilities suggests further elaboration of a network of cooperating institutions linking the institutions that can create the knowledge and technology, the institutions with a responsibility for its creation, and the natural customers and users of the results: government at all levels, academic institutions, and businesses. All have roles to play in creating and using ocean knowledge.

Some excellent institutions, such as the the Joint Oceanographic Institutions, and the Consortium for Oceanographic Research and Education, and several professional societies, link the academic research institutions with each other and with the Federal agencies. The Sea Grant program has provided a mechanism for linking academic institutions with states and local communities and with businesses. There is an opportunity and a need to expand and extend these mechanisms and networks. There is a clear government need at the federal level, and the scale of the oceans and ocean problems makes national activity both required and sensible. There is a need at state and community levels, and an opportunity for ocean related businesses to contribute and to benefit, and for new businesses to be created.

The key to making knowledge and technology available to businesses and localities, and to incorporating their knowledge into the needs of the Navy and other federal agencies, is direct contact between those who are generating the knowledge and technology and those who might use the results. We need more mechanisms for direct contact and discussions. Others are more expert than I am in the design of such systems, but the key requirement is the facilitation of conversation and discussion between those with knowledge and technology and those with needs for their use. "Arms length" mechanisms are neither satisfactory nor sufficient; there must be direct, detailed informal discussion over a period of time if the real needs are to be understood, and the really relevant knowledge and technology to satisfy the needs are to be identified. The people involved really have to work closely together.

Continuing the role of the Federal agencies in funding and stimulating the creation of ocean knowledge and technology, and the use of this knowledge by state and local governments and by businesses is implied by the nature of the problems and possibilities of the oceans, by our national and local relationships to the oceans, by our strong academic institutions working on ocean problems, and by the possibilities for using the knowledge and technology for strengthening ocean businesses and creating new ones. We have an opportunity for strong mutual support among a variey of segments of our society, drawn together by an important piece of our national and planetary environment.

Mr. WELDON. Thank you, Dr. Frosch. And our final witness, the former CNO and former Secretary of Energy, and currently the Executive Director or head of CORE, Admiral Watkins.

STATEMENT OF ADMIRAL JAMES D. WATKINS, USN [Ret.], CONSORTIUM FOR OCEANOGRAPHIC RESEARCH AND EDUCATION

Admiral WATKINS. Thank you, Mr. Chairman, Chairman Saxton, Chairman Rohrabacher, and members of the subcommittees.

On behalf of the nearly 40 academic oceanographic institutions of the Consortium for Oceanographic Research and Education, referred to by prior witnesses as CORE, I'd like to thank you for this opportunity to testify at this special watershed hearing.

Before going on, I'd like to bring to the attention of the chairmen of the committees the fact that in my formal statement, I attach statements from NASA, from DOE, USGS, MMS, and EPA, who could not be here today at the table—we just didn't have a long enough table. But I want to tell you how important they are to the contribution of national science research in the oceans.

They represent about 25 to 30 percent of the funding base for this nation. And therefore, it cries out for some kind of an additional partnership between us, to make sure that we bring all of the federal agencies together. They all make a contribution. They aren't that redundant. They do work together. But we can do it better in the future.

I've been asked to wrap up today's hearing and discuss follow-on actions that we should take to answer the call of this hearing today to leverage national oceanographic capabilities better, including their public visibility, as well as their contribution to important national goals.

Now we've heard insightful testimony this morning from witnesses that represent the cross-section of the highest levels of leadership in the oceanographic community. And several clear and important messages were presented to you.

From those messages, ocean science is clearly contributing to the overall well-being of the nation. But we can do more in the years ahead.

We're at a critical juncture in attempting to match ocean science and technology to growing societal needs. We stand at a point which was made earlier by others, where we need to decide the fate of the ocean sciences for the year 2000 and beyond.

Now a quarter of a century ago, a major presidential commission reshaped the federal oceanographic establishment. One major result was the coupling of oceanographic and atmospheric research and the formation of NOAA.

Now oceanographic research has matured. Twenty-five years ago, much of the ocean research was driven by the Cold War. The idea of satellites for oceanographic use was a pipedream at that time. We had no inkling that an entire self-sufficient ecosystem could thrive on hydrothermal vents, one of the most severe environments on earth, as Dr. Ballard testified.

As we've heard today, changes in the way we utilize and value our oceans and coastal areas are now driving the potential for many new applications of ocean science and technology and placing many new demands on the nation's investment in these areas. These changes have taken place during an era of level funding of the basic oceanographic research, as we have shown on the graph.

It has remained at a constant $525 million in FY '95 constant dollars for 12 years, even as the total investment in basic research in the United States has doubled.

As a result, ocean sciences now represent less than four percent of the total federal basic research budget, down from the seven percent in Fiscal '82.

I am quick to point out, having made that statement, that in my wanderings about Congress in preparation for these hearings today, I was asked by so many—did anybody ever ask the Congress? Did anybody ever bring this to their attention?

The answer is no.

There hasn't been any unified spokesperson for the oceans in this country. There have been tremendous leaders in the various agencies fighting for what they think is right, cut back by OMB for budget realities. But in aggregate, we've not done a good job in highlighting this.

I give credit to the space agency for bringing together this nation and exciting the Congress of the United States and the people in that area. And I applaud the almost daily reports in the Washington Post about colliding nebuli, the fact that we're going to blow up in 5 billion years.

Those are exciting things.

But, on the other hand, I don't think that those kinds of things are necessarily going to solve the doubling of the population of this globe by the middle of the next century. And those are the things we have to face now.

And we recognize that we're not going to have the dollars available, possibly. So, therefore, leveraging current and future capabilities in new ways is a logical must.

Now you've heard people describe what science needs to be done. And I believe we have excellent organizations in this country to contribute—the federal agencies, academic institutions—the National Academy of Sciences pulls together.

We know what to do. We don't know how to do it when we have this broad-based integration that needs correction. So I'm going to talk about how best to perform the science in a more efficient way.

Now Dr. Alberts testified about his excellent report of 1992 called "Oceanography in the Next Decade." I consider that to be a watershed report. It's a clear direction to the community, the academic community, and it deals with a redefinition of what that oceanographic community is in the context of societal needs.

Basically, the report says to the academic institutions, get your act together. Speak with one voice and support national priority programs. And we're really doing that, but not as powerfully as we could.

It was in this context, then, of that report, with the support and supervision of the National Science Foundation, NASA, ONR, ARPA in the Department of Defense, and the Department of Energy, and over 100 scientists and other experts from the ocean science and technology community representing federal agencies, academia and industry, were brought together by my organization, CORE, for the Interagency Partnership Initiative. The idea was to lay the groundwork for carrying out the challenges of the NRC report where integration within the ocean science community can add value to all connected partners and increase mission effectiveness and efficiencies of the agencies.

This approach does not interfere at all with the pursuit of unique missions and programs of the individual federal agencies.

The result of this exercise is the report, "Oceans 2000"—I'll steal Dr. Frosch's copy—that I sent to the members of these committees up here before this testimony. It's called "Oceans 2000: Bridging the Millennia—Partnerships for Stakeholders in the Oceans." And the report identifies a broad realm of research opportunities embedded in the themes of quality of life, economic development, education/communications and national security.

The ultimate conclusion of the report is a set of recommendations in three general area—a set of partnership opportunities where cross-decking of research information is essential, a management blueprint to carry that out, and the encouragement of the direct involvement of Congress as key partners.

Specific partnership areas were defined, including data collection, declassification, quality control, sharing of community resources including people, laboratories, research platforms and computing capabilities. And partnerships in formal classroom education, using the oceans to integrate teaching of classical scientific disciplines, and informal education raising the awareness in the general public of the importance of oceans to our nation.

The management blueprint provides a mechanism for integrating the federal agencies and nonfederal agencies to help provide the desired level of effectiveness and cost efficiency in the execution of federally-funded ocean science and technology programs.

We've taken lessons learned from the excessively top-heavy and cumbersome structure that caused the early demise of the prior councils of the '50s and '60s.

Today's hearing proves that our proposed simplistic three-tiered structure can work as it has done for the past two years in bringing this report to fruition. Invoking the partnership principle of high-level involvement, there needs only to be the kind of oversight body of the principal operational federal agencies, with ex-officio membership from the federal administration, academic, industrial, and other nonfederal sectors that you see here today.

So, basically, we're running a pilot program today for what we've recommended in our Oceans 2000 report.

The critical nature and high visibility required of the partnership activities dictates continued involvement by this level of representation. And we've called this body, basically what you see here today, with those other five agencies that could not be present because of size today, we've called this body the National Ocean Leadership Council. And while informal in nature, we believe it should be a chartered organization by the Congress.

Finally, Congress has a direct role to play in this effort. First, we recommend establishment of a Congressional Task Force, very much like you've done here today.

The nine federal agencies with ocean-related missions and funding needs operate under the direction of more than 40 authorization, oversight and appropriation committees and subcommittees in the House and Senate.

And I have up on the board—you can't see it, but I've provided in your notes to each of the members here today that these 47 committees need not fear the fact that we come together and talk in broad terms about ocean science.

We believe that they can continue to carry out their heavy responsibilities for individual agency funding and those linkages with academia and the private sector in the normal fashion.

But at least once a year, let's talk about broad national strategy before the kinds of committees that you've brought together here today, Mr. Chairman.

A congressional task force brought together, much as you have done, then, would provide a forum of information exchange at least once a year for addressing broad strategies for more effective coordination of ocean science and technology issues. Task force membership should cut across many, if not all, of the cognizant congressional bodies.

And by the way, I have talked to your colleagues in the Senate. I think they're ready to move in a similar fashion—both sides of the aisle, bipartisan, strong support for what you're doing over here in the House.

And I think your leadership is to be commended and I believe the Senate will follow. This will provide a very powerful signal, I think, to our country that we're getting serious about the island nation that we live in.

Individual agency programs and budgets would continue to be addressed, as I said, but under the broad rubric of strategic coordination where appropriate to efficient execution of programs.

To bring this concept to fruition, the Congress should pass an Ocean Partnership implementing legislation. This legislation should support the continuing definition, development and implementation of partnerships in oceanography that can provide the impetus needed at critical times.

Without such an integrated Congressional Ocean Task Force approach, our proposed National Ocean Leadership Council, that you see the embryo form of here today, would have little meaning and the current fractionated system would be forced to continue unchanged.

The United States is looked up by the world as a leader in both technology and policy for the marine environment. And nearly 30 years ago, this island nation took a bold step forward in redefining our national investment in ocean sciences through the implementation of the recommendations of the Stratton Commission.

The time for facing a broad set of challenges by re-examining our nation's posture towards ocean science and technology is upon us. I hope that the hearing today will serve as the first step in this process, and there is a grand opportunity for us to work together and build a better future for the nation through the oceans.

The answers to many of our most pressing problems can be found in our greatest natural resource, the oceans.

Thank you, Mr. Chairman.

[The prepared statement of Admiral Watkins follows:]

Testimony of

Admiral James D. Watkins, USN (Ret.)

President, Consortium for Oceanographic
Research and Education

presented to the

House National Security Committee
Subcommittee on Military Research and
Development

House Science Committee
Subcommittee on Energy and Environment

House Resources Committee
Subcommittee on Fisheries, Wildlife and
Oceans

January 25, 1996

Admiral James D. Watkins, U.S. Navy (Retired)

President, Joint Oceanographic Institutions
and
President, Consortium for Oceanographic Research and Education

Admiral Watkins became President of the Joint Oceanographic Institutions (JOI) in September 1993. JOI collectively represents the world's ocean research institutions and has been at the forefront of coordinating the international collaborative research programs in deep ocean sampling since 1976. He also serves as President of The Consortium for Oceanographic Research and Education (CORE), a group established on October 1, 1994 and dedicated to help provide an effective and unified voice, at the national level, in support of institutions, public and private, that make up the U.S. ocean science and technology community.

Prior to his work at JOI and CORE, Admiral Watkins served under President George Bush as the sixth Secretary of Energy (1989–1993) and as Chairman of the Presidential Commission on the Human Immunodeficiency Virus Epidemic (1987–1988). As Secretary, he helped to develop the first comprehensive National Energy Strategy.

Born in 1927, James D. Watkins graduated from the United States Naval Academy (1949), received his Master's degree in mechanical engineering (1958), and completed a reactor engineering course at the Oak Ridge National Laboratory. He became the twenty-second Chief of Naval Operations as selected by President Ronald Reagan in 1982. His tours as a flag officer included Chief of Naval Personnel, Commander of the Sixth Fleet, Vice Chief of Naval Operations, and Commander-in-Chief of the Pacific Fleet. He has been decorated with several Distinguished Service and Legion of Merit medals as well as the Bronze Star with combat "V."

Admiral Watkins combines extensive military experience, proven administrative skills, and a vast knowledge of the ocean sciences and our educational system.

Chairmen and members of the Subcommittees, on behalf of the 36 member institutions of Consortium for Oceanographic Research and Education (CORE) I would like to thank you for the opportunity to testify at this important hearing.

We've heard insightful testimony this morning from a very distinguished panel of witnesses. This panel represents some of the highest leadership and best minds the scientific community has to offer. I think that several clear messages have been presented. First, our Nation's long-term investment in oceanographic science and technology has paid enormous dividends in the past:

Predicting El Nino events and their devastating effects on regional climates (droughts, floods, and crop yields) and fisheries;

Maintaining superiority in undersea surveillance and antisubmarine warfare;

Providing the fundamental concepts related to the beginning of life forms on earth, which can in turn, lead to discoveries in such important fields as biomedicine;

Saving hundreds of thousands of lives through forecasts of coastal hazards (including tsunamis and hurricanes);

Establishing a whole industry based upon commercially viable fish farms and aquaculture facilities; and

Locating and building oil platforms to maximize production and to survive the extremes of the ocean environment.

These and other advances have been major factors in the winning of the Cold War, the development of billions of dollars in revenues for coastal communities from tourism and marine industries, the savings of lives and mitigation of tremendous property damage from accurate hazard prediction and well-mapped shipping routes.

We've heard from the Navy, the National Science Foundation and the National Oceanic and Atmospheric Administration how these factors affect the roles and missions of their agencies. We've heard from experts discussing relationships of the government with industry and academia. We would have liked for the other agencies who have a significant role in oceanographic science and technology to have been here today. Unfortunately, time constraints prohibited the Environmental Protection Agency, the National Aeronautics and Space Administration, the Minerals Management Service and the US Geological

Survey from joining us here at this table. I took the liberty of consulting with the leaders of these agencies about today's hearing and asked them provide me statements of their agency's role in ocean science and technology to be presented before the committee. I have attached each of these statements to my testimony.

We have also heard today that changes in the way we utilize and value our oceans and coastal areas are now driving the potential for many new applications of ocean science and technology and placing many new demands on the Nation's investment in these areas. Changes in world geopolitical structure, movement of population within our own borders to the coasts, and the increasing reliance on the seas for food and other material goods are leading to new economic sectors, the need for new technological capabilities and educational methodologies and increasing concern about the impact of man's activities on the marine environment.

These changes have taken place during an era of level funding of the basic oceanographic research. As shown in the attached graph, Federal funding for basic ocean research has remained constant for the past 12 years ($525 million in constant FY1995 dollars), even as the total investment in basic research in the US has doubled. As a result, ocean sciences now represent less than 4% of the total Federal basic research budget, down from 7% in FY 1982.

But where do we go from here? The 7% investment of ten years ago gave us outstanding products. The decline of this level by one-half is simply not adequate to support the needed high quality scientific research "waiting in the wings" especially in light of the ever broadening scope of applications for ocean research. Clearly a stronger investment is needed for the broader set of challenges before us in the next millennium.

As Dr. Alberts has testified, in 1992 the Ocean Studies Board of the National Research Council (NRC), recognizing the need to revisit the status, roles and plans of the oceanographic community, convened several meetings and prepared their assessment. Their report, entitled "Oceanography in the Next Decade: Building New Partnerships," has been a watershed event in the direction of this community. The objectives of the study were to "document and discuss important trends in the human, physical and fiscal resources available to oceanographers, . . . to present the best assessment of scientific opportunities during the coming decade, . . . and to provide a blueprint for more productive partnerships" (NRC, 1992).

The report of the National Research Council was particularly timely in that it dealt with the redefinition of the oceanographic community in the context of society's changing needs. In opening remarks launching the National Research Council's report its Chairman, Dr. Frank Press, cited the marked changes taking place in this post-cold war period that seem to cry for new approaches to partnerships in the oceanographic scientific community. In fact, as he pointed out, "concerns about the ocean as a medium for warfare as a threat to national security are decreasing while environmental problems of the coastal zone and understanding how the ocean controls climate are of increasing importance." Further, he states that while "major advances in understanding the ocean in the development of technologies for observing it have set the stage for much greater research achievements," this comes at a time when "resources necessary to obtain this understanding are increasingly scarce." Hence, the Ocean Studies Board thought it important to undertake the study of where marine science found itself today and where it needed to head tomorrow.

The NRC report established a broad "framework in which improved partnerships . . . can sustain the advances of the past, and lead our country and the world to greater understanding of the many roles the ocean play in human life." That report and continuing activities of the NRC have served to define, in a well reviewed manner, what science should be done in the ocean. And Dr. Alberts' testimony has re-affirmed that. My discussion focusses on how to accomplish these science objectives.

Partnerships have been deemed a particularly useful mechanism in oceanography as the issues being addressed are generally large in scale (in terms of geography, complexity, or time and resources required) and partnerships are a very effective means to overcome those hurdles unique to ocean science including security concerns, distributed ownership of resources, complications in communications within the community and a severe lack of public awareness of the importance of the oceans to society. Additionally, partnerships have proven effective as evident from the successes cited earlier in this testimony. For these reasons, we are compelled to study past successes (and failures) and apply any lessons learned to future efforts.

Therefore, it is in the foregoing context that, with the support of NSF, NASA, ONR, ARPA and DOE and with oversight and review by a high-level Coordinating Group of community leaders, over 100 scientists and other experts from the ocean science and technology community, (represented by Federal agencies, academia, and industry), were brought together in the CORE Interagency Partnership Initiative to establish a new and reinvigorated partnership concept. The idea was to lay the groundwork for carrying out the many challenges outlined within the NRC report where integration of more than one of these participating communities can add value to all connected partners and increase mission effectiveness and efficiency.

Four broad themes deemed highly relevant to society's needs and therefore our national interests, were used as a defining structure for this effort. The themes were:

1. National Security - Ensuring that national interests are guaranteed at home and abroad and that basic and applied ocean science remains an essential element of this assurance. This category is meant to include issues associated with preservation of our national interests, via military defense, and foreign policy support.

2. Economic Development - Use of the basic and applied knowledge of the ocean and its resources for economic gain, including attention to marine resources, transportation, recreation, and development, and related industries.

3. Quality of Life - Health and social well-being of people as derived from using basic and applied knowledge of the ocean. Subject material includes the topics of preservation/improvement/stewardship of the environment (pollution prevention, cleanup and remediation), shoreline protection, coastal hazard mitigation and recreation.

4. Communication/Education - Conveying an understanding of the importance of oceans to national decision making, to the public at large, and to decision makers and educators at every level using basic and applied knowledge of the oceans, to include the exploitation of state of the art electronic networking and computer based simulations/demonstrations.

The results of this exercise are publicly introduced at this hearing in the report "Oceans 2000: Bridging the Millennia - Partnerships for Stakeholders in the Oceans." The report identifies a broad realm of research opportunities defined by the diversity of issues embedded in the subjects of quality of life, economic development, education/communication and national security. It is quite noteworthy that for the purposes of defining partnerships, several consistent themes emerged which are discussed in the report. The pervasive nature of these themes lends strong credibility to the partnership approach; there is an implication that a partnership developed to address a problem in one area will provide collateral benefits to other applications.

Finally, the report identifies a set of hurdles to the establishment of an effective and efficient integrated national ocean science and technology strategy and recommends specific actions to accelerate and improve the applicability of ocean research to national interests.

To this end the following three recommendations are made:

New Partnership Opportunities - The Operators

Definition of specific research and education opportunities for partnerships between and among academia, industry and the Federal government: These partnerships should adhere to the principles cited in the report, and should focus on optimizing the use of data, resources and educational/communication tools. The partnerships should include potential involvement by all sectors of research and education. Specific partnership areas were defined including: data collection, declassification, and quality control; sharing of community resources including people, laboratories, research platforms and computing capabilities; and partnerships in formal (classroom) education, using the oceans to integrate teaching of classical scientific disciplines, and informal education raising the awareness in the general public of the importance of the oceans to our Nation.

Management Blueprint - The Executive Branch

Integration at the Federal agency and non-Federal agency levels: Develop and implement an integrated Federal agency to non-Federal agency partnership management plan to help provide the desired level of effectiveness and cost efficiencies in the execution of federally-funded ocean science and technology programs. Invoking the partnership principle of 'high-level involvement', there must be a long-standing oversight committee of the principal operational Federal agencies, with ex-officio membership from the Federal Administration, academic (including the National Academies), industrial and other non-Federal sectors. The critical nature and high visibility required of the partnership activities dictates continued involvement by the highest level representatives of the agencies. This **National Ocean Leadership Council** (NOLC) should be a chartered organization under legislation defined below.

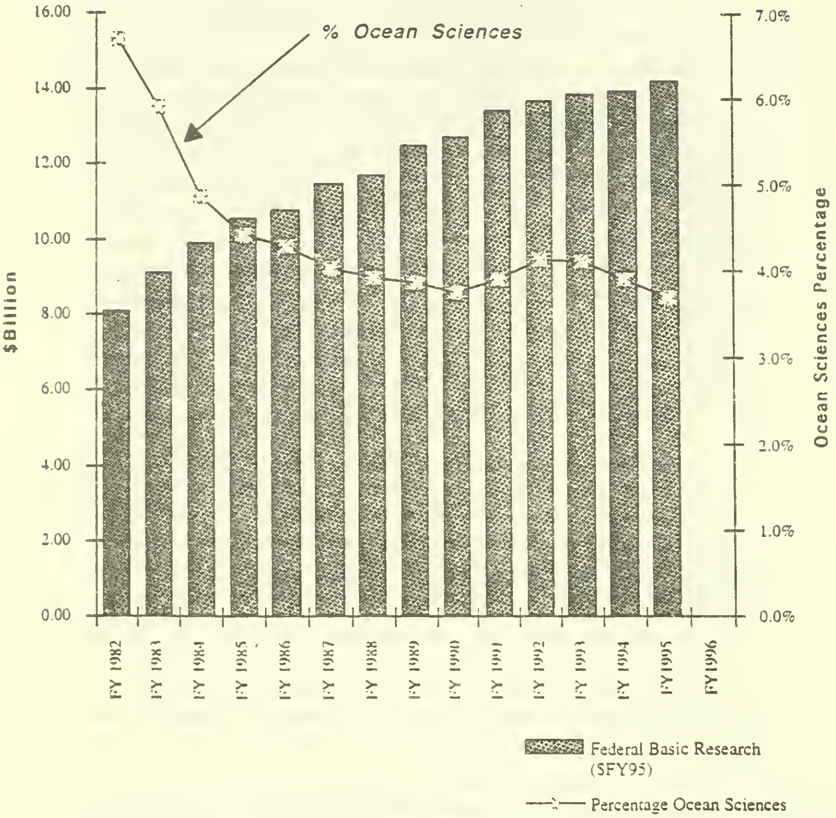
Congressional Involvement - The Legislators

(1) Involvement of Federal legislators: Federal agencies operate under the direction of more than forty authorization, oversight and appropriation Committees and Subcommittees of the House of Representatives and Senate. In light of the breadth of national missions driving ocean sciences, a strategic focus for broad Congressional interests is urgently needed. A Congressional task force would provide a forum of information exchange for addressing broad strategies for more effective coordination of ocean science and technology issues. It will also provide an opportunity for members of Congress to understand the oceans impact on the many business and social sectors that are associated with national defense, economic growth, and quality of life. Task force membership should cut across many if not all of the cognizant Congressional bodies. Individual agency programs and budgets would continue to be addressed as they are today, but under the broad rubric of strategic coordination where appropriate to efficient execution of programs.

(2) Ocean Partnership Legislation: The oceanographic community is not limited in its ideas for implementation of new partnerships. The visibility required to launch this partnership initiative can be accommodated through the development of a Congressional ocean task force. Backing must come in the form of substantive support, arguably in the form of supporting legislation. Legislation supporting the definition, development and implementation of partnerships in oceanography will provide the impetus needed at a critical time. Without such an integrated Congressional task force approach, the proposed National Ocean Leadership Council would have little meaning and the current fractionated system would be forced to continue on its less than cost-effective path.

The United States is looked upon by the world as a leader in both technology and policy for the marine environment. Nearly thirty years ago this nation took a bold step forward in redefining our national investment in ocean sciences, through the implementation of the recommendations of the Stratton Commission. The time for the reexamination of our Nation's posture towards ocean science and technology is upon us. I hope that the hearing today will serve as the first step in this process. There is a grand opportunity for us to work together and build a better future for our Nation. The answers to many of our most pressing problems can be found in our greatest natural resource, the oceans.

US Federal Basic Research (Constant $FY95)



AGENCIES INVOLVED IN SUPPORT OF ACADEMIC OCEAN SCIENCES RESEARCH COMMUNITY

(Source is the Ocean Studies Board of the National Research Council.)

AGENCY	MISSION WHICH IS SUPPORTED BY OCEAN SCIENCES RESEARCH	$M TO ACADEMIC OCEAN SCIENCES RESEARCH in FY95	APPROXIMATE NUMBER OF SCIENTISTS SUPPORTED
NSF	Basic research in all disciplines	193.37 (37%)	1500
ONR	National security	103.21 (20%)	800
NOAA	Fisheries, weather, coastal zone management, navigation	79.50 (15%)	600
EPA	Pollutant dynamics, environmental protection, environmental monitoring	41.00 (8%)	300
NASA	Ground truthing for satellite observations of sea surface; large scale oceanographic observations	38.90 (7%)	300
USGS	Coastal erosion and hazard mitigation, mapping, hard mineral resources	36.49 (7%)	250
MMS	Exploration and development of oil and gas resources on outer continental shelf	13.40 (3%)	100
DOE	CO_2 budget, energy sources and transport	11.30 (2%)	85
ARPA	Advanced technology demos, industry coordination	7.00 (1%)	50
USACoE	Ports and harbor management, dredging	negligible	negligible
USCG	Coastal search and rescue, law enforcement	negligible	negligible
Oceanographer of the Navy	Operational navy - systematic characterization and forecasts of environmental conditions	negligible	negligible
CIA	Access/exploitation of declassified data	negligible	negligible
	TOTALS	**$524.17M**	**2100 (see note)**

Note: The total number of scientists does not equal the sum of the numbers in the column, since most scientists receive funding from multiple agencies

Table 1

OCEAN SCIENCE CONGRESSIONAL JURISDICTION

House of Representatives
(10 Committees, 17 Subcommittees)

- **Appropriations**
  - Commerce, Justice, State and Judiciary (NOAA)
  - Defense (ONR, ARPA)
  - Energy and Water (DOE)
  - Interior (USGS, MMS)
  - VA, HUD and Ind. Agencies (NSF, NASA, EPA)
- **Budget** (all agencies)
- **Commerce**
  - Energy and Power (DOE)
  - Health and Environment (EPA, NOAA)
  - Oversight and Investigations (EPA, DOE, NOAA)
- **Government Reform and Oversight**
  - Nat'l Economic Growth, Nat'l Resources and Reg. Affairs
  - National Security, Int'l Affairs and Criminal Justice
- **National Security**
  - Military Research and Development (ONR, ARPA)
- **Resources**
  - Energy and Mineral Resources (USGS, MMS)
  - Fisheries, Wildlife and Oceans (NOAA)
- **Science**
  - Basic Research (NSF)
  - Energy and Environment (NOAA, EPA, DOE)
  - Space and Aeronautics (NASA)
- **Intelligence** (DOD)
- **Transportation and Infrastructure**
  - Water Resources and Environment (EPA)

Senate
(8 Committees, 12 Subcommittees)

- **Appropriations**
  - Commerce, Justice, State and Judiciary (NOAA)
  - Defense (ONR, ARPA)
  - Energy and Water (DOE)
  - Interior (USGS, MMS)
  - VA, HUD and Ind. Agencies (NSF, NASA, EPA)
- **Armed Services**
  - Acquisition and Technology (ONR, ARPA)
- **Budget** (all agencies)
- **Commerce, Science and Transportation**
  - Oceans and Fisheries (NOAA)
  - Science, Technology and Space (NSF, NASA)
- **Energy and Natural Resources**
  - Energy Research and Development (DOE)
- **Environment and Public Works**
  - Clean Air, Wetlands, Priv. Prop., Nuc. Safety (EPA)
  - Drinking Water, Fisheries and Wildlife (NOAA)
- **Governmental Affairs**
  - Permanent Investigations (all agencies)
- **Select Intelligence** (DOD)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JAN 11 1996

OFFICE OF
RESEARCH AND DEVELOPMENT

ADM James D. Watkins, USN (Ret.)
President, Consortium for Oceanographic
Research and Education
Suite 800
1755 Massachusetts Avenue, N.W.
Washington, D.C 20036-2102

Dear Admiral Watkins:

Thank you for your kind offer to present at the hearing of the House of Representatives National Security, Resources, and Science Committees the contribution EPA is making to the science of oceanography. Clearly, the organizers of this hearing have chosen wisely by inviting you as President of CORE to speak on behalf of agencies like EPA which a striving to advance ocean sciences. I am pleased to offer the following summary of the EPA contribution to this crucial area of science.

The EPA Office of Research and Development has created a strategic planning process that will focus our contribution to science on the greatest technical uncertainties in environmental risk assessments. Using the risk assessment paradigm as a basis for technically-defensible environmental decisions, I have established support for ocean sciences, in part, through a new $100 million extramural, investigator-initiated grant program for our colleagues in the academic community and through an intramural research program that includes three marine laboratories as part of the EPA National Health and Environmental Effects Research Laboratory. Our efforts in ocean science seek to understand the factors that control the biointegrity and sustainability of critical marine resources. EPA is developing models of the effects of urban centers on coastal benthic communities, primary production, and commercial fisheries. EPA is spearheading research on the effect of toxic chemicals such as endocrine disruptors on the health of marine fish, mammal and wildlife communities. In addition, EPA is establishing research program to understand the influence of pollution stress on the

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outbreaks of disease in corals and other critical marine ecosystems.

Please do not hesitate to call me at 260-7676 if you wish additional information for the above outline of our ocean science program. Thank you again for representing the research of EPA at the these important hearings.

Sincerely,

Robert J. Huggett
Assistant Administrator

United States Department of the Interior
MINERALS MANAGEMENT SERVICE
Washington, DC 20240

OCT 24 1995

Admiral James D. Watkins, USN (Ret.)
President, Consortium for Oceanographic
Research and Education
1755 Massachusetts Avenue, NW
Suite 800
Washington, DC 20036

Dear Admiral Watkins:

Thank you for inviting the Minerals Management Service to provide information on our contributions to ocean science research. We are quite proud of the accomplishments of the MMS Environmental Studies Program over the years and are pleased to provide you with this brief description of the program.

One of the primary responsibilities of the MMS, as specified in the Outer Continental Shelf Lands Act Amendments of 1978, is to oversee the safe and environmentally sound exploration, development, and production of offshore natural gas, oil, and other mineral resources on the Nation's Outer Continental Shelf (OCS). Since 1974, MMS has conducted research in the ocean sciences to identify and evaluate potential environmental problems associated with offshore activities and to monitor the effects of those activities on the environment.

Over the last decade, MMS has made a conscious effort to develop partnerships with the academic research community to address our needs for high quality scientific information. We are particularly proud of the MMS Coastal Marine Institute initiative which has established partnerships through the States of Louisiana, California, and Alaska to support important research in the state universities. In recognition of the mutual benefits derived through CMI research, the participating States share the costs on an equal basis with MMS. These university cooperative efforts educate and train young scientists and utilize the expertise of senior scientists to improve our knowledge of fundamental ecological processes and develop workable solutions to environmental problems. Pioneering research in the use of marine organisms as bioindicators of environmental conditions, biodegradation of petroleum hydrocarbons, and bioremediation for oil spill cleanup are some of the topics studied through partnership at the CMIs.

In addition to leveraged agreements, MMS has numerous other cooperative agreements with State institutions. For example, Scripps Institute of Oceanography is conducting a major multi-year study of physical oceanography in the coastal ocean off southern California. This and several other physical oceanographic efforts have been designed to maximize partnerships with programs in other agencies such as NOAA, ONR, NSF and DOE. Much of the MMS ocean science program has involved developing a better understanding of marine ecosystems and marine environmental monitoring. Some of these efforts are now conducted for MMS through a partnership with the NBS.

In summary, the MMS has many active partnerships and looks forward to new opportunities for partnership to meet the many demands for scientific information to support the OCS Program. The costs of oceanographic research are great, and with ever-increasing scrutiny of federal budgets, it becomes more important than ever to seek out cooperative ventures.

Please contact Dr. Ken Turgeon, Chief, Environmental Studies Branch, at (703) 787-1717 if you would like clarification or additional information on the environmental studies program and our research partnerships with State and local governments, academia and other Federal agencies.

Sincerely,

Cynthia Quarterman
Director

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Reston, Virginia 22092

In Reply Refer To:
Mail Stop 915

OCT 3 1 1995

Admiral James D. Watkins, USN (Retired)
1755 Massachusetts Avenue, NW
Suite 800
Washington, D.C. 20036-2102

Dear ~~Admiral Watkins~~ Jim:

In response to your memorandum of October 11, 1995, enclosed is a brief description of recent U.S. Geological Survey (USGS) activities in the ocean sciences.

We appreciate your taking the opportunity to include the USGS contributions to ocean sciences in your testimony and share your excitement that a call for such a hearing may lead to increased emphasis on the ocean sciences.

If we can be of further assistance, please let us know.

Sincerely yours,

Gordon P. Eaton
Director

Enclosure

U.S. Geological Survey
Role in Ocean Sciences

As the Nation's earth science information agency, the U.S. Geological Survey's (USGS) role in ocean sciences is to provide geologic information and expertise pertaining to the Nation's coastal and offshore lands. The U.S. coastal ocean is critical to the economic well being of the Nation. These areas are used for transportation, recreation, and waste disposal; provide energy and non-metallic mineral resources for the Nation; and provide habitat for most of the commercial fisheries resources. In addition, natural hazards, such as coastal erosion, earthquakes, landslides, and major storms, pose potential threats to people, property, and the environment in coastal areas. A large and growing population along our coastlines is placing increasing stress on the coastal ocean environment. The impact of both human activities and natural processes must be documented and assessed in order to develop workable management strategies for the Nation's coastal realms and marine Federal lands. USGS research and mapping activities in the marine realm are conducted under four themes: Environmental Quality, Natural Hazards, Natural Resources, and Information and Technology. Environmental research addresses the geologic issues which influence the long-term quality and preservation of marine environments. Specific issues addressed include: pollution and waste disposal, fragile environments, including coastal wetlands, marine reserves and biologic habitats, and geologic records of environmental change, including past climates. Natural hazards research is conducted to better understand the frequency and distribution of catastrophic events and the geologic processes acting in the affected coastal regions. Specific issues addressed include: coastal erosion and offshore earthquakes and landslides. Natural resources research aims at providing an understanding of the distribution of mineral and energy resources in our marine and coastal realms and of the processes that control their composition, origin, and availability. Information and technology activities provide reconnaissance sea-floor mapping of the U.S. Exclusive Economic Zone as well as information management and dissemination services. Through a series of regional and fundamental studies conducted in partnership with other Federal and State agencies and academic institutions, USGS develops a description and understanding of marine and coastal geologic systems to address issues of societal importance.

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001

Admiral James D. Watkins, USN (Ret.)
President
Consortium for Oceanographic
  Research and Education
1755 Massachusetts Avenue, NW
Washington, DC 20036-2102

Dear Admiral Watkins:

Thank you very much for the opportunity to include information on NASA's role in ocean sciences in your statement at the upcoming Tri-Committee Hearing on Advancing Oceanography through Partnerships. A summary description of NASA's ocean programs is enclosed.

NASA is very pleased to say that we, together with our national and international partners, are in the final stage of completing a set of dedicated missions that demonstrate our ability to observe the global ocean. Indeed, NASA's oceans missions are an essential part of NASA's Mission To Planet Earth program, a space-based global observation system supporting the U.S. Global Change Research Program, the coordinated U.S. interagency program designed to provide the scientific basis for understanding global change.

We appreciate your hard work and enthusiasm in building partnerships in oceanography and look forward to continuing to work with you on ocean science issues.

Sincerely,

Daniel S. Goldin
Administrator

Enclosure

NASA's Ocean Remote Sensing Program

The dynamics of the ocean are important in the evolution of the Earth's climate and key to providing vital information to areas of human health and welfare such as weather, shipping, fisheries, pollution, river discharge, and sea level rise. However, data and information collection from the oceans is particularly difficult due to the vastness of the oceans as well as the general inaccessibility of many parts of the ocean. NASA, through the unique vantage point of space, uses satellites to provide data on a global scale that would be impossible to obtain otherwise.

In 1985, NASA was challenged to develop an oceanography from space program in the publication: Oceanography from Space: A Research Strategy for the Decade 1985-1995 (JOI) . NASA , together with national and international partners, is in the final stage of completing a set of dedicated missions that demonstrate our ability to observe the global ocean. NASA has been very successful in achieving this goal. In addition, NASA has also played a key role in developing algorithms and other space-based oceanographic data sets through partnerships with other agencies and other countries.

NASA's ocean missions are an essential part of NASA's Mission To Planet Earth (MTPE), a space-based global observations system supporting the U.S. Global Change Research Program (USGCRP), the coordinated U.S. interagency program designed to provide the scientific basis for understanding global change. The centerpiece of NASA's MTPE program is the "Earth Observing System" (EOS) which is a series of satellites, to be launched in 1998, developed for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans.

NASA's ocean missions and activities address a central goal of using space-based remotely sensed data to establish the global ocean's physical and biological natural variability on seasonal to decadal to centennial time scales, to monitor the ocean environment for changes and trends, and to provide data and information on a timely basis to scientists, decision-makers, and the many other users of our data.

The primary missions designed by NASA and its partners to observe the oceans are comprised of several different kinds of sensors which measure an important set of ocean science variables. These are TOPEX/POSEIDON, NSCAT, SeaWIFS, MODIS (on EOS) and a unique calibration/validation experiment called SIMBIOS which will collect and merge the diverse data from seven overlapping international missions to create a common data stream. In addition, a number of other missions are already providing critical data and information on ocean-related processes such as sea-ice processes (AVHRR, ESMR, SMMR, SSMI, ERS and Radarsat), ice sheet mass balance and sea-level change (ALT, GLAS, SAR, etc.), and other ocean, ice, atmosphere exchanges. These space-based observations will ultimately be correlated and combined with complementary ground-based and in-situ data and information collected by other agencies and countries to create the most complete scientific picture possible under the USGCRP and other international global change research programs.

TOPEX/POSEIDON, one of NASA's most successful Earth science missions, is the first space mission specifically designed and conducted for studying the circulation of the world's oceans. The mission is a joint effort between NASA and the French space agency (CNES) to observe global ocean circulation for 3-6 years using an Earth-orbiting satellite. A state-of-the-art radar altimetry system is being used to measure the precise height of sea level, from which information on the ocean circulation is obtained. The satellite, launched on August 19, 1992, has been making observations of the global oceans with unprecedented accuracy since late September 1992. The main science goal of the mission is to improve the knowledge of the global ocean circulation to an extent that will ultimately lead to improved understanding of the oceans' role in global climate change. Other applications include global sea-level rise, ocean tides, geodesy and geodynamics, ocean wave height, and wind speed.

A second international partnership mission between NASA and our Japanese colleagues will result in the launch in 1996 of the NSCAT (NASA Scatterometer) as one of several important sensors on the Japanese ADEOS mission. ADEOS has, as its mission, to acquire data on worldwide environmental changes such as the greenhouse effect, ozone layer depletion, tropical rain forest deforestation, and abnormal climatic conditions. NSCAT, a specialized microwave radar designed to measure winds over the oceans, will measure wind speeds and directions over at least 90 percent of the ice-free global oceans every 2 days under all weather and cloud conditions. Winds are a critical factor in determining regional weather patterns, global climate, and general circulation of the world's oceans. At present, good capability for weather data acquisition exists over land but not over oceans, where our only knowledge of surface winds comes from infrequent, and sometimes, inaccurate, reports from ships. Studies of NSCAT data are expected to lead to improved methods of global weather forecasting and modeling and to a better understanding of environmental phenomena (such as El Nino) that greatly affect world economies.

Thirdly, NASA is poised to announce the upcoming launch of SeaWIFS (Sea-viewing Wide Field-of-View Sensor) on Orbital Sciences Corporation's SeaStar spacecraft which will address the crucial measurements associated with changes in water color, or spectral radiance, that accompany the growth of phytoplankton (microscopic plants, the base of the food chain) and suspended sediments near the surface waters of the ocean. SeaWIFS will bring to the ocean community a welcomed and improved renewal of the ocean color remote sensing capability lost when the Nimbus-7 Coastal Zone Color Scanner (CZCS) ceased operation in 1986. Designed to monitor ocean physics, chemistry, and biology from space, SeaStar represents a new generation of highly capable, low-cost satellites planned as part of NASA's Mission to Planet Earth. The SeaWIFS ocean color sensor, followed by MODIS on EOS, will provide the fast, repeated global coverage required for advanced studies of marine phytoplankton and ocean surface currents. Phytoplankton form the base of the food chain, and ocean color observations from space let us estimate the concentrations of these algae over large and remote ocean regions worldwide and permit the study of near surface phytoplankton "blooms". These sudden episodes of plant growth (blooms) attract fish and alter ocean chemistry. In addition, the phytoplankton drift with ocean currents, and, therefore, long-term ocean color data help trace these currents, providing information needed for navigation and safety at sea. These data also reveal the fate of river discharge, pinpoint fishing grounds, and track water-borne pollution. Such knowledge is of high operational value to shipping and fishing fleets, other commercial organizations, and Government agencies.

Finally, NASA and several international partners, in a brand new way of doing business, have just begun a new space initiative called SIMBIOS that will provide a special data set from a series of seven different ocean color sensors from different countries (beginning with the launch of SeaWIFS). The success of the earlier ocean color mission (which revolutionized the way in which biological oceanographers view the ocean) led to a number of follow-on satellite sensor mission, within the US and from the European Space Agency, Japan, Taiwan, Germany and France. While several of the instruments are highly complementary, there are significant differences in technical approach which precluded comparisons among the various valuable data sets. SIMBIOS is an international, interagency calibration/validation initiative which ultimately makes the data compatible. SIMBIOS results in the development of a long-term (nearly 20 years) set of consistent time-series of global bio-optical products from the world ocean available to the world oceans community. The presence of multiple ocean color sensors will allow the eventual development of an ocean color observing system that is both cost effective and scientifically based. The data set will present a unique opportunity to understand the coupling of physical and biological processes in the world ocean and help provide answers to ocean issues which directly impact humans on a daily basis.

Department of Energy
Germantown, MD 20874-1290

ADM James D. Watkins, USN (Ret.)
President, Consortium for Oceanographic
Research and Education
1755 Massachusetts Avenue, N.W.
Suite 800
Washington, D.C. 20036

Dear Admiral Watkins:

Subject: The role of the Department of Energy in ocean science is to support interdisciplinary studies on the dispersal and fate of energy-related materials in the marine environment.

Thank you for your letter of October 11, 1995, to Dr. Martha Krebs informing us of the tri-Committee hearing on advancing the science of oceanography through partnerships. I appreciate the opportunity that your testimony will provide for acknowledging the Department of Energy's contributions to ocean science. In addition, I agree that during these times of fiscal constraint, government downsizing, and program reengineering, it is extremely important that partnerships be developed to help coordinate our research and development efforts. Such partnerships are also necessary to ensure the efficient use of distributed capabilities and resources.

The Department of Energy and its predecessor agencies have supported long-term interdisciplinary studies in ocean science as part of the concern about the sustainable development of energy resources and the dispersal and fate of energy-related materials (including radionuclides, trace metals, synthetic organics, hydrocarbons, and most recently CO_2) in the marine environment. It is believed that the ocean may be a large sink for emissions of atmospheric CO_2 resulting from energy production via fossil-fuel combustion and that carbon is an important currency for marine ecosystems and for marine resources.

The Office of Health and Environmental Research is currently supporting university and national laboratory scientists to conduct molecular to global-scale studies to:

- define oceanic sources and sinks in the global carbon cycle;
- quantify the biogeochemical mechanisms and processes by which carbon is assimilated, transported, and transformed in the coastal ocean; and
- understand and predict the natural variability of the ocean and coupled ocean-atmosphere systems on decade and longer time scales.

Printed with soy ink on recycled paper

I hope this information will help in your preparation for the upcoming tri-Committee hearing. Should you chose to include it in your written statement, I have enclosed a statement to this letter that outlines the role of the Department of Energy in ocean sciences in more detail than provided above. Please let me know if I can be of any further assistance.

Sincerely,

Ari Patrinos
Associate Director for Health
and Environmental Research
Office of Energy Research

Enclosure

ROLE OF THE DEPARTMENT OF ENERGY IN OCEAN SCIENCE

The Department of Energy supports long-term interdisciplinary studies in ocean science as part of its concern for the sustainable development of energy resources and the dispersal and fate of energy-related materials (including radionuclides, trace metals, synthetic organics, hydrocarbons, and most recently CO_2) in the environment. It is believed that the ocean may be a large sink for emissions or atmospheric CO_2 resulting from energy production via fossil-fuel combustion and that carbon is currency for marine ecosystems and for marine resources. The Office of Energy Research, through the Office of Health and Environmental Research, is currently supporting university and national laboratory scientists to conduct molecular to global-scale studies within four coordinated ocean-science components.

(1) *Produce a global description of the oceanic carbonate system* for quantifying ocean sources and sinks for atmospheric CO_2 and for linking global ocean-atmosphere and carbon-cycle models. This research is conducted in partnership with the Joint Global Ocean Flux Study (JGOFS) and the World Oceanographic Circulation Experiment (WOCE).

(2) *Develop advanced instrumentation, new molecular-biological techniques, and mathematical models* for, respectively: measuring the ocean's physical, chemical, biological, and optical state and obtaining high frequency *in-situ* measurements of the factors affecting carbon fluxes; examining how organisms adapt and respond to environmental stresses associated with energy-related activities; and predicting changes in the CO_2 content of the ocean and atmosphere that may result from fossil fuel combustion.

(3) *Conduct an integrated multidisciplinary field experiment in U. S. coastal waters* (Ocean Margins Program) in FY 1996 to assess the sources, sinks, transformations and exchange of carbon and other energy-related materials at the land/ocean interface and thereby increase the fundamental understanding of the impact of energy-related activities on coastal ecological systems.

(4) *Develop the models necessary to predict accurately* climate change on decade and longer time scales and to understand the natural variability of the ocean and coupled ocean atmosphere systems (the DOE Program for Climate Prediction): The Semtner-Chervin global ocean model has been recognized internationally and adapted to perform coupled model runs as part of the 1995 international climate change assessment. In FY 1996, coupled atmosphere-ocean-land surface-sea ice models based on the next generation component models will be completed and ready for use in climate prediction and climate change assessment. The near-term objective is to provide verified, high resolution coupled models that will simulate the global climate of the last century, including measures of variability, without flux correction or climate drift.

During these times of fiscal constraint, government downsizing, and program reengineering, the Department of Energy agrees that it is extremely important to develop partnerships between the federal agencies, private industries, and academic communities to coordinate research and development efforts and to make efficient use of distributed capabilities and resources. Such coordination is an integral part of the Department's activities in ocean research and in global change research in general.

Mr. WELDON. Thank you, Admiral Watkins. And let me thank each of you for your outstanding testimony. And as we've heard today, not only are we graced with the presence of the major federal agencies involved with ocean jurisdiction, but we also have from Admiral Watkins those agencies who could not be at the table because of the magnitude of the hearing, but who are committed to this process that we're beginning.

And let me say it is an historic time because, in a bipartisan way, the three subcommittees that are here that share jurisdiction on the issue of oceanography have each committed themselves to work to try to support you legislatively with the kinds of recommendations that you will bring forth to allow us to better coordinate our resources.

Admiral Watkins, as I've discussed with you on several occasions, that may well lead to a piece of legislation such as you've suggested, that will not involve massive amounts of new money, perhaps, but simply a better and easier way to coordinate those dollars we're already spending and perhaps those resources we're already providing.

But we will guarantee you one thing, and I will guarantee you this personally from my own standpoint—the focus will be on the oceans as we proceed through 1996 and beyond, and not just in the security area, and Admiral Boorda knows he has our unequivocal support, but also in the environmental area.

In the meeting in St. Petersburg, meeting with the ambassador for the environment for Canada, John Fraser, and Lord Stanley Clinton Davis from the British Parliament, we discussed the issue of the oceans and we could not understand how our respective countries, if you're a supporter of defense, you're considered perhaps to be against the environment. Or if you're for the environment, perhaps you're not for defense.

Well, we're going to take a new approach. We're going to be for both.

We're going to be for those areas where we can cooperate, where we can build new partnerships, build new ways of coordination and understanding, and attempt to tear down some of the barriers that have existed in each of the agencies and operations to better serve the people of this country.

Excellent testimony. I have a number of questions. I'm going to defer to the chairman of the science subcommittee while I go over and vote.

We will continue the hearing during that vote so members can go over.

You're not going to stay? Okay. Then we're all going to go over and vote together and we'll be back in five minutes.

We'll recess the hearing.

[Brief recess.]

Mr. WELDON. The subcommittees will be reconvened. Would the distinguished panelists take their chairs so that we can begin questioning?

Our intent is to proceed right through the noon hour and to allow members to ask questions so that our witnesses may get on with their schedules, which we know are very busy.

So we will just continue to proceed through the question session.

I have one question I'd like to begin with while Mr. Rohrabacher is returning. As I mentioned in my opening comments, I've submitted for the record both letters from Al Gore and from Trent Lott from the Senate, both of whom are aware of these hearings, the series of hearings, as well as this hearing today, and have expressed their support for the initiative that we're undertaking.

Senator Lott had a specific question in his letter to me, dated January 11th, which I'd just like to raise and either have a response now or a response for the record.

In his letter, and I'll refer to it, it says, and I quote: "With your hearing being focused on leveraging national oceanographic capabilities and meeting requirements in nontraditional ways, it would be interesting for you to query the panel to see if the Navy can partner with the university research ship fleet to help reduce its survey backlog of 240 ship-years. This approach would help expand partnerships and synergy among the nation's oceanography community and provide much needed money to expand ocean science research."

This question comes out of a report that Senator Lott had commissioned in last year's defense authorization bill which was submitted to the Secretary of the Navy and prepared by the oceanographer of the Navy.

So perhaps Admiral Boorda or anyone else, Dr. Lane, or whoever else would like to respond to this question of Senator Lott, I'd appreciate it.

[Letters from Vice President Al Gore and Senator Trent Lott appear in Appendix II, pages 199 and 200 respectively.]

Admiral BOORDA. I'd be happy to respond.

We've had some discussions with the Senator. He and I have exchanged some correspondence on that.

The 240 ship-years of work is a valid statement. It is one of the reasons that in our CNO executive board, I decided to keep more ships.

I'm going to ask Paul or perhaps George if they'd like to go further on how we might best reduce that backlog faster. Clearly, that's our aim.

In many of the places, however—let me caveat it before he speaks—in many of the places, only ships that are under our control can go in the area under current international law.

Admiral GAFFNEY. Mr. Chairman, we have right now a plan to field by the end of next fiscal year eight ships permanently deployed overseas that can virtually get into any area that we want.

And as the CNO just mentioned, a normal research ship, a marine scientific research ship, can't necessarily go every place we can.

So I think we're pretty set for the future in that we have fewer ships, but they're great ships. They're probably the greatest ships built today.

We would look for opportunities, I think if we have a little extra cash now and then to use and buy time from academic ships. That's something that I will always ask for in the Navy and we'll see what we can afford.

But those opportunities exist and we'll watch for them. Thank you.

Mr. WELDON. Thank you. Yes, Dr. Ballard? That will be one of the areas we'll look to help you with as well during the budget process.

Dr. Ballard?

Dr. BALLARD. Yes. Another, I think, if one wants to look into the advances being made in telecommunications to be able to use telecommunications for scientists in the laboratories on shore to access ships at sea while they're working.

I think it's not possible for the oceanographers to go on a long cruise that has multiple purposes for that limited time window when they might want to do their work.

We certainly know that in the private sector, the advances in telecommunications are really advanced now and that scientists should be able to access military platforms or other platforms without physically having to go there.

And I certainly know that the Department of Defense has very sophisticated telecommunications technologies that they might want to look at how to use those in a nonclassified way to provide access to their platforms, or anyone's platforms, without having to physically put people on the ships.

Mr. WELDON. Excellent suggestion. And I would ask, Admiral Boorda, if you could provide for the record some overview of the potential in that area for that kind of coordination in the future.

Admiral BOORDA. We'd be happy to. That's exactly the kind of initiatives we're looking for.

[See Appendix for the information supplied by Admiral Boorda.]

Mr. WELDON. Thank you very much. With that, I have other questions, but I will defer to our panelists who have a number of questions. And with that, I'll start with our chairman of our Science Subcommittee, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman.

First of all, I want to commend you, Mr. Ballard. Your vision of what can be the potential of the ocean, I know that some people think that the ocean is something to be preserved and to keep people away from.

Being a surfer, I know that the ocean is there for all of us to enjoy and to preserve, but also to use for the benefit of mankind.

I think your vision of an ocean in the future that can be put to use for the benefit of all mankind is very acceptable—not acceptable—but an admirable vision.

Interestingly enough, I thought that it paralleled some of the vision that people have for space, and I am also on the Space Subcommittee.

Do you think that there's enough cooperation going on between the space communities and the oceanographic communities?

Dr. BALLARD. I think the trend is in the right direction. I think there's much more cooperation now than in the past. And as I say, all evidence suggests that there will be more.

Certainly, NASA has trained its technology and its incredible resources not only into outer space, but back on to earth itself. A lot of cooperation.

I might add that I grew up in Long Beach and got my diver certification in Belmont Shore. So I've lived the world that you've lived in.

I think a thing that has not been mentioned here today, I wear a number of hats, and one of them is as the founder of the Jason Project, the Jason Foundation for Education.

It's very important that we not only learn about the oceans through the combined efforts of the various organizations here today. It's also critical that we work together to prepare the next generation of oceanographers and scientists and engineers and legislators.

I think the Jason Project is a good example of leveraging, in that we've gone out and most of the funding into this educational program is from the private sector. We've gone out to corporate America, who are concerned about the supply of engineers and scientists in the pipeline. We have a wonderful collaborative effort with the United States Navy in providing the assets under the SECNAV initiative for access to assets in the use of the NR-1 and their support ship this summer.

We're also working with NOAA in that access of the Habitat Program.

But I must point out that if you want—those of us who are known as risk-takers, those of us who are known as going on to the edges of the system and breaking new frontier, as I feel comfortable doing as an explorer, if we go out and we get industry to put $5 million into a program, if we go out and develop collaborative efforts with the Navy to leverage their assets, and if we go out and work with NOAA and work with 12,000 science teachers—we have students in Pennsylvania, we have students in every district that is represented by these committees right now studying oceanography.

We cannot then pull the plug on the program.

We've made a tremendous investment with private industry and the military assets, to only now not have the Habitat in question that we have 500,000 kids studying right now, and 12,000 teachers.

Mr. ROHRABACHER. The greatest guarantee of not pulling the plug on the program of course is to make sure that there's as many people contributing to the pot as can be, and not just the federal contribution.

Dr. BALLARD. The vast majority of the funding on this project is private, the private sector.

Mr. ROHRABACHER. Right. When I asked you about space and the cooperation, are you aware, or is anyone aware on this panel of the initiative taken up at the Ames Laboratory that is trying to develop a spacesuit that will be also a deep sea diving suit?

Dr. BALLARD. We've been working with Ames, but we've been mostly working with their robotic vehicles.

Mr. ROHRABACHER. Mr. Baker?

Dr. BAKER. Yes, I am aware of that initiative, which has been an important one because it's an application of NASA technology to deep sea diving.

In fact, Sylvia Earle, who is a former chief scientists at NOAA, has been involved in advising on that project.

Mr. ROHRABACHER. I'm a scuba diver as well as a surfer, and I think it's important for us to realize that a lot of the training that's being done in order to help build things in space are actually being done first in the ocean to train these folks how to handle construction in a different gravity situation.

I am a little bit concerned, and I will put this for the record, Mr. Chairman, that it's something we should look into that the efforts to build a space suit and a dive suit have been actually thwarted, I believe, by some of the bureaucratic impediments in NASA, and that we should actually be looking at that to make sure that that isn't thwarted.

Finally, I'd just like to, Mr. Baker, about the NOAA fleet, which you made passing reference to. And I'd like to ask our naval representatives this:

Can't the Navy provide NOAA some help here so we don't have to have a separate NOAA fleet and Navy fleet? And to the degree that you can, can't we just charter some people from the private sector?

Dr. BAKER. Mr. Rohrabacher, that's a topic of great concern and interest to us. You and I have talked about this before——

Mr. ROHRABACHER. Yes, we have.

Dr. BAKER. (continuing) trying to have an efficient operation, operating within what we know are very tight budget constraints.

We have to go to sea to do our work. We have to have people out there. I think we all agree that that has to happen.

Mr. ROHRABACHER. Sure.

Dr. BAKER. The question is how do you do it?

We have a plan that allows us to, we think, utilize the best of all the ways in which the nation can go to sea. That is, with government-owned assets, with private industry, and with the academic community.

And our current ship plan—remember that NOAA originally started out with a fleet of 25 ships that were government-owned and government-operated.

Our current plan is to have a mix of ships which would come either from the government, from private industry, or from academia, and each time that we look for a ship, we look at the cheapest way to do it.

This could be the Navy. This could be the academic community. It could be private industry. And in fact, as you look at the NOAA fleet, we have three major functions. We have fisheries, we have mapping and charting, and we have research.

We will be looking to the research community to help us with research ships. We will be looking to the private industry to helping us with mapping and charting. And we'll probably have a mixture of these for fisheries.

But we have a process in place that allows us to look at the cheapest way to do it in each case. And it may well be that the Navy can provide us some help. We don't have a formal arrangement at that point. The Navy has worked very closely and built up the academic community and has had a very strong relation. We have close relations with the Navy.

So this is something that we're working on.

Let me just say one thing about the space side.

Mr. ROHRABACHER. Yes.

Dr. BAKER. You mentioned that. This is an area that has been very important. It has allowed us to do new things on the ocean we simply couldn't do before.

We have close ties between NOAA and NASA, but also between NOAA and the Navy because the Navy does operational satellites and has done some wonderful things. This latest popular science has some pictures in it of the GEOSAT satellite and the data that the Navy released.

NOAA has been working with the Navy on making those maps.

We have a new program which is allowing us to leverage the assets that other countries are flying. One of the points that you made to me was can't you leverage the assets that other countries are using?

We have a small program, a very small percentage of our total budget that allows us to leverage ocean satellites flown by other countries so we can get that data out to private industry and to the academic community, and it's working great.

So we appreciate your help on that.

Mr. ROHRABACHER. Thank you, Mr. Baker. Admiral, I imagine you agree with that.

Admiral BOORDA. Well, there's not a lot to add to that, except to say that when we went from 12 ships to eight, and we were actually lower, that was done based on affordability and on our view of the mission and how it fit with other things we have to do in the Navy.

In the end, our charter is combat-readiness, the ability to understand the oceans and the environment, in our view, is primarily related to being able to project power and do the things we need to do.

And as we do that, the cooperation with NOAA and with the other agencies is a very good thing for us to do and makes us better at what we do.

Taking a mission that is not inherently a national defense mission and trying to do it in a way that we do business would probably make it more expensive, would make us grow and have you begin to think about putting appreciably more money into our budget in that area, and would require us to hire an awful lot of people right at the time when we're trying to downsize.

So I think a cooperation between the two of us is much preferable to a hostile take-over between the two of us.

[Laughter.]

Mr. ROHRABACHER. Thank you very much. Thank you, Mr. Chairman.

Mr. WELDON. Thank you, Mr. Rohrabacher. I might just add, during the budget deliberations of last year, when the question came up of the down-sizing of the NOAA fleet and some of the missions there, we asked the oceanographer for the Navy to give us a written response because some in this Congress are under the impression that we can eliminate an agency and the mission just goes away, when in fact what happens, it gets shifted to somebody else.

And so, it's not just a dollar savings in that one agency because, in effect, you're putting new responsibilities on somebody else.

We've got to make sure in this current budget environment that we don't do that, or at least if we do it, we understand what the implication is and the impact in this case of the Navy taking on something that they hadn't been responsible for in the past.

So in some cases, we're getting a false sense of savings in this area that really, I think, has yet to be borne out. In the case of the oceanographer and the written response I got, there was no savings at all. It was an increased cost to perform missions that have been done by NOAA.

Mr. Rohrabacher, one of the things that you could do to help us is to sensitize members of Congress and perhaps conduct surfing classes for us out on the West Coast.

Would you do that?

[Laughter.]

Mr. ROHRABACHER. You're all invited.

[Laughter.]

But Mr. Ballard, I would suggest that, you know, surfing gets a lot of attention, and deservedly so because it's a great sport. But I'm also a scuba diver. And I will say that that sport, too, is a really significant sport in terms of the amount of money being made in terms of people who are teaching other people how to scuba dive, equipment, et cetera. So it's an important economic factor.

But I believe that scuba diving is becoming something now that is really opening up a new understanding of this underwater universe for so many people who 20 years ago would never have been included in this.

It all was sort of "Sea Hunt" years ago. We remember that. So, sure.

Mr. WELDON. Admiral Watkins, did you want to respond to a scuba diver comment?

[Laughter.]

Admiral WATKINS. We've been hurt by scuba diving and congressional funding in the past. And so, I want to avoid that.

[Laughter.]

What I wanted to add to Mr. Rohrabacher's question, though, was the fact that NASA joined our consortium to try to bring new visibility to the ocean component of Mission to Planet Earth, the earth observing system. It was 70 percent of the earth. If you're going to go observe it, let's include the oceans.

If you include the oceans, let's correlate it with the ship data, the buoy data, the other data we're getting so that we have ground truth correlation so that we can begin to build the models.

And so, it's a new start for NASA in a way. They've been hamstrung, to a certain extent, by the funding debates, by the reorganizational things. I've talked to Dan Goldin a number of times on this.

I think we have to get serious about the oceans as being part of that mission. And that's where the cooperative effort between Navy, NOAA, NASA, the academic institutions can be brought together. It's when you begin to correlate that data.

And we're getting it all over the place now, with all kinds of small observatories in the water that we need to correlate. And so it's extremely important we not forget that.

I've talked to some of the appropriators for NASA on this issue who were almost caught offguard, like what is the ocean component of Mission to Planet Earth?

So I think we have to air those kinds of things and we recognize that with funding problems, it's going to be a problem, but let's start it up. Let's do it even on a modest basis and get it into our system.

And that's the kind of integration that I think is important with NASA.

Mr. KENNEDY. Mr. Chairman?

Mr. WELDON. Yes?

Mr. KENNEDY. Mr. Chairman, if I could just interject here.

Mr. WELDON. Oh, yes.

Mr. KENNEDY. Because it's on this subject.

Rhode Island was the first to embark on this with the help of Administrator Goldin and with the Baykeeper in Narraganset Bay. We're going to take the satellite technology that comes from the pictures of the earth and 380 different colors, correspond each of those colors to a different characteristic—salinity, water temperature, the coastal environment—and you've got a holistic picture of the bay, where the most productive areas are for shell fishing and the like, where the currents are coming and going.

It's just going to do wonders for coastal zone management. It's a unique idea of sharing satellite technology, Mission to Planet Earth, with what we're trying to do with this. I think it's a perfect example.

In fact, it's only through the initiative of ASA, which is a private company in Rhode Island, that is going to develop the simulation models and make a commercial application of this.

And I can guarantee you that there's going to be a great commercial application for this when you think of all that can be developed from this knowledge of where the best place to harvest aquaculture is, or things of that sort.

Mr. WELDON. Thank you, Mr. Kennedy.

Our next questioner is from the Natural Resources Oversight Subcommittee on Ocean Issues and has been a tireless champion since he's been a member of this Congress, and long before that on ocean issues.

His state is what has given me my sensitivity to the oceans because I spend part of my summers there. The distinguished gentleman from New Jersey, Mr. Saxton.

Mr. SAXTON. Thank you, Mr. Chairman. I just want to note at the outset that Mr. Rohrabacher—I'm sorry he left. I just wanted to let him know that I'm a sailor and a fisherman and a clammer.

And my staff has determined that I have twice as much coastline as he does.

[Laughter.]

Each of you has indicated a commonality, and I might say without exception and I think it's actually quite good that many of us are on a common wave of thought relative to where we ought to go with ocean science and environmental research.

The notions that you have conveyed here this morning I think are particularly important in terms of partnerships and partnershipping and enlarging peripheral vision and seeing what each other are doing.

It is absolutely productive and a concept that I've believed in for a long time. I would just like to point out and ask you to do something, if you would.

Earlier this year, the Resources Committee reported a bill that would reorganize the National Oceanic and Atmospheric Administration subsequent to the supposed demise of the Department of Commerce. And as part of that bill, we wrote in a provision which moved toward what you all think we ought to do in terms of setting up perhaps a formal way to cooperate with each other.

We would have established in Subtitle F the National Institute for Aquatic Resources, which was an attempt—of course, it didn't survive the leadership process because we're of course not into expanding government at this point. But it is a concept which I believe I heard each of you talk about today, not in these terms, but in terms of the cooperative research and development efforts that we ought to be promoting.

So I would just like to ask you, and I will provide you each with a copy of this probably through the mail, I'd like to ask you each for your comments relative to this. And maybe we could just use this as a kind of a model to say, okay, well, this is certainly the concept and we're certainly headed in the right direction. But obviously, we've got to do certain things differently because we did this quickly, I must admit.

Secondly, I'd also like to ask you to take a look at something that Mr. Weldon and Mr. Kennedy and Mr. Gilchrist and I have been working cooperatively on. It is in the form of a bill, number H.R. 2827.

And essentially, this bill would consolidate environmental science activities that are found throughout the Federal Government and in certain other private institutions, to consolidate and improve governmental environmental research by organizing a National Institute for the Environment, once again, in a slightly different area—that is, environmental research and our understanding of environment.

And if we had a panel of people who were from environmental and scientific organizations here today, they would have espoused the same common theme. We need to know what each other are doing. We need to be able to help each other. We need not to duplicate what each other are doing. We need to increase our peripheral vision. We need to be partners in this effort.

This bill, interestingly enough—and I was going to read the preamble, which I'm not going to do. But it says all the same things that you all said.

So I would like to ask you if you would take a look at this bill as perhaps a model as well for creating an ongoing formal partnership, if you will, and give us some input as to what you think about it.

And I would just conclude this by saying this, and any of you can comment if you like.

Fifty years ago, in another area of science, we realized the same thing. We realized that we were doing research and development on issues that had to do with health in hospitals all across the country, in colleges and universities all across the country, in drug and pharmaceutical companies all across the country.

And Congress said, oh, why don't we coordinate all this? And we created the NIH.

I think, as Mr. Weldon and Mr. Kennedy and Mr. Gilchrist do, and perhaps others who are here as well, that it is high time that we recognize that science has the same application to the environment, that science has the same application to ocean policy as it does to health policy. And it ought to be our business to help create that partnership.

So these are two of the efforts that I've been involved in, in fact, leading, and I would love to have your comments in your own due course to get back to us on them.

Thank you. And if any of you want to comment on these issues, feel free.

Mr. WELDON. Anyone like to respond? We would certainly want you to respond for the record. But does anyone want to respond now?

[No response.]

Thank you, Mr. Saxton. We'll move along to—and I'm going in the order of arrival. Don't blame me for the order. This is staff, when you have to mix three subcommittees.

So the order I have here is Roemer, Gilchrist, Bateman, Kennedy, Johnson, Meehan, Taylor, Minge, Ehlers, Farr, Foley, Tanner, Cobin, Longley, and Olver.

So if I've missed someone, let me know, if we don't have everyone.

So, Tim?

Mr. ROEMER. Thank you, Mr. Chairman. And I'll begin by telling you I'm going to even begin to try to compete with Mr. Saxton or Mr. Rohrabacher for scuba diving or fishing or surfing awards, being from Indiana, where we don't have a lot of coastline.

[Laughter.]

But as Admiral Boorda knows, being from South Bend, Indiana, we play a mean game of football in the water and the snow. So we do have some credentials here.

[Laughter.]

And seriously——

Admiral BOORDA. If I can interrupt.

Mr. ROEMER. Sure, Admiral.

Admiral BOORDA. You do have one guy from South Bend who's got a lot of ocean and who's a sailor, also. So we may be able to beat him if we join forces.

[Laughter.]

Mr. ROEMER. Yes. I like having you on my side, I've got to tell you.

[Laughter.]

It has been a very enlightening hearing for me, with the expertise from this panel of distinguished witnesses. We have certainly heard with a great deal of unanimity that the oceans are critically important.

There is not the same kind of unanimity up here. I don't believe that this kind of important research can sustain or be sustained, and as Dr. Ballard said, we cannot continue to be the leader in the world in these areas if we have to implement up to 33 percent cuts.

Now, Admiral Watkins, I think, outlined this very well. In 1982, ocean sciences received about seven percent of the U.S. federal basic research dollar.

In 1996, that's going to be probably less than 3.8 percent.

Dr. Baker, aren't you extremely worried about this, and are these too deep of cuts?

Dr. BAKER. Yes, they are deep cuts and we are worried. We have been trying to address that issue of getting adequate resource into ocean research and into ocean management for a number of years. We have been only partially successful in what you have seen.

I think we're facing a real problem here.

Mr. ROEMER. Where are they too deep, specifically?

Dr. BAKER. Well, you can look across NOAA and you can listen to the other agencies, but we have three areas of oceans that are particularly important to us. One is the area of the coastal zone. And you do have an important coast in Indiana, a Great Lakes coast. Coastal zone management. We have fisheries. And we have the role of the ocean in weather and climate.

All of these are areas that have a direct impact on our economy. They're all areas where the more we know, the better job we do of managing for economic growth. And yet, we simply don't have the adequate resources to do the job.

Now I recognize that we're all working under the balanced budget limits. But I believe that it is very important for us both to try to have a focus of resources in oceans, and also I think to try to build stronger partnerships with the private sector.

We see some very good opportunities in dealing with the private sector, and as we go forward with any kind of arrangements, I think it is very important to bring them in.

This is one way, I think, in which we can help leverage the resources that we have.

Mr. ROEMER. Admiral Watkins—I want to come back to some partnerships. Maybe Admiral Boorda and you, Dr. Baker, can address that.

But Admiral Watkins, what is your opinion on the severity of these cuts?

Admiral WATKINS. Well, having lived in the oceans for 37 years in the Navy, both on it and under it, and having watched us win the Cold War, in my opinion, because of our incredible science and technology base in this country and what we did to lay out a strategy against the Evil Empire that clearly brought them to their knees, I know how powerful the oceans are—in transportation, in the very threat of El Nino alone, for example, where NOAA has done a tremendous job in giving us some kind of a model to predict.

That's not just for coastal hazards and humans. That's also for agriculture. It's also for water management. It's also for predicting where is our airstream going to go in the winter months.

Do we position our energy supplies properly? There's a whole host of reasons why we need to know about an interannual or even seasonal projection of climate.

That's going to come from the oceans. There are very few people in this country that understand that oceans drive the climate. And in the Arctic, the heartpump of the world, we know very little about it.

The Navy probably knows more about the Arctic than any other community.

We need to share that data. We need to get it out. We need to really understand it, or we're not going to know what natural variability is in all this clamor here on Capitol Hill on whether it's anthropogenic or not, whether it's man-created.

We're got to really understand nature, and we don't. We've underserved the nation's oceans for a long time. We are in a malaise because the Evil Empire was driving 40 percent of the entire investment in R&D and the oceans within the Navy.

Now that's not the case. They've been cut in half. They're only 20 percent now. NSF has the largest portion of the responsibility.

So we have to regroup our thinking.

And I think it's very important that we listen to people like the National Academy of Sciences, who just put out a report, and I think that Bruce Alberts talked about it today. Allocating federal funds for science and technology.

And what they're saying is, let's have a new way of doing business about this. Let's don't talk about R&D and put it together at a $70-billion level for the Federal Government when we're putting $14 billion into research, not $70 billion. A lot of that is "D," it's not "R."

And so we have to understand what we're doing here. A lot of that is test and development in the military. Very important. I'm not degrading that. But we have to understand what we're doing.

And they're saying, let's tell Congress what we're doing in science and technology and let's get into themes that we want to be pre-eminent in the world in.

And this is one of them, in my opinion.

Mr. ROEMER. I would interpret your answer to say that you're very concerned about these.

Admiral WATKINS. Strong letter follows, yes.

[Laughter.]

Mr. ROEMER. Good. Let me ask a follow-up question.

We've heard very good testimony about what some of these research vessels have been able to accomplish, what satellites have been able to accomplish.

Dr. Ballard talked about JASON and ARGO, although they might not fall into the same category in terms of cost. The ones that I mentioned up front are very costly and expensive technologies.

How do we better coordinate these disparate services so, as Admiral Boorda talked about cooperation in the academic life and in our university life, how do we come up with enough capital funding to continue to buy satellites, to buy research vessels, to produce the next generation of JASONs and ARGOs?

What ideas might the panel have in that area? Let me start with you, Dr. Ballard.

Dr. BALLARD. Well, in fact, development of the ARGO/JASON system was a Cold War development effort. It was funded by the United States Navy, the Office of Naval Research, the Office of Naval Technology, and tremendously augmented by the operational

Navy that had specific missions that needed this kind of technology base.

I think it's important, too, to point out that in that particular technology which was developed by the Navy, it has now been transitioned from the Navy to the operational side of the academic community and the academic community now has full access.

It's a very wonderful example of cooperative work, where the National Science Foundation is now funding research using those assets.

I think, though, it's a very important point to point out, is that we're not as technology-limited as we were ten years ago or 15 years ago.

To me, one of the biggest concerns I see is the ability to go to sea. What's the sense of having all of these assets? What's the sense of having all of this technology if we're going to see less than we used to go to sea?

I certainly know in the 30 years that I've been on the Woods Hole Oceanographic Institution, we're not as a scientist at that institution going to sea as much as we used to be because it's becoming more and more difficult to get into the ocean.

And so I think it's very important to make sure that we're maintaining an oceanographic fleet that lets us get out there. At any one time, I think that presently, there are four manned assets in the world that can reach the average depth of the ocean.

Imagine—four assets in the world that can reach the average depth of the planet.

And so, on a good day, you might have 12 people down there. And so we must move forward in not only using manned vehicle systems, but move into the use of robotic systems, but use the telecommunication technology to access this area.

And so it's very important that we are a sea-going research community and that's why ships and the gasoline that goes into them are very important to us.

Mr. ROEMER. And your point is that this project was 100 percent government-funded, and then only after success, leveraged private-sector dollars and academic dollars.

Dr. BALLARD. Correct. That's mostly in the uses of it.

But if you look at the development of deep submergence, which I've been a part of my entire life, the United States Navy has been the leader in the development of deep submergence technology, has led the way in providing those capabilities for the academic community. It was the Office of Naval Research that made ALVIN possible many, many years ago. And it's only after that you can take these risks that have no apparent commercial value to them, initially, that then you can break the groundwork.

But I must point out that Lewis and Clark had a hell of a lot of trouble getting money from you gentlemen as well, and that exploration is a very difficult process.

Many of us, if you look at the history of President Jefferson, he finally had to use his own money to sponsor Lewis and Clark to go and look at the Louisiana Purchase.

Mr. ROEMER. Dr. Ballard, I was not here then.

[Laughter.]

There may be other members of this panel that were.

[Laughter.]

Dr. BALLARD. But I simply want to point out that it's very important that we are out there. We're not normally out there. We don't have gills. And we must make sure that if we're going to utilize the ocean, that oceanographers are able to get in the ocean.

Mr. ROEMER. Let me just conclude with a final question to Admiral Boorda, if you can just kind of wrap up my limited questioning here.

How might you help us with suggestions to create better partnerships between all these agencies with a limited amount of resources? And how might Congress respond with our own reorganization better to that?

Admiral BOORDA. I think Admiral Watkins has the right idea. That isn't just because I used to be his executive assistant. I think he has the right idea.

[Laughter.]

Admiral WATKINS. I have to—now it's a conflict of interest.

[Laughter.]

Admiral Boorda, I threatened him that if he didn't testify properly today, I would change his fitness report that's sitting out at St. Louis in the archives out there when he was a young captain who I trained as my executive assistant.

[Laughter.]

So, with that comment, you can go ahead.

[Laughter.]

Admiral BOORDA. I thank Admiral Watkins. In fact, CORE does have the right idea.

Having us meet, having the Navy have executive boards, having hearings like this are all helpful. But we need to make this a routine way of doing business, where we get together, work out our problems, come to you and tell you what we can't work out and where we need help, where you think about it in ways that only you can think about it and come to us with guidance and help and we have a good interchange.

I don't think that happens in an ad hoc way. I think something has to be done to make it more routine.

I was listening to Dr. Ballard answer your question. One of the bad parts about having so many people come with you is they all have things they give you and you can't possibly read them all in time.

But it's interesting that this whole list of things I got, as people said, gee, tell them this, are things where it is exactly opposite, where the situation has shifted and the community is no longer dependent upon us for getting it started and doing it. But we are now dependent upon someone else and worried about the cuts in their funding.

So we're mutually interdependent now. A couple of these notes I got are interesting because they talk about satellites which we no longer control. We did during the era that Dr. Ballard was talking about. But now we've combined. And so we take data from DOD, the Air Force, and NOAA. And so cuts to NOAA's satellite programs are important.

The national data centers that NOAA runs are a major source of information we need that we put in the Fleet Numerical Weather Center—we call it the MITOC center now—out at post-graduate school. And if that slows down, that's combat-readiness-related stuff that I will be back again in another committee, in Congressman Weldon's committee, saying, you saved the money over here. I need this stuff. And I will have to recreate it at added cost.

So we are so interdependent, we need to make these discussions a routine way of doing business, both in the Congress and among us.

Mr. ROEMER. Thank you, Admiral.

Thank you, Mr. Chairman.

Mr. WELDON. Thank you, Mr. Roemer, and that certainly is a lesson that we need to hear in this Congress, that we don't need false savings, that we need to know the long-term impact of decisions we make.

And with that, we'll turn to the gentleman from Maryland, Mr. Gilchrist.

Mr. GILCHRIST. Thank you, Mr. Chairman.

Admiral Watkins, the suggestion by Congressman Saxton of a National Institution of Environment or perhaps a National Institute of Ocean Studies or something like this, is that, in your mind, something that's necessary as a congressionally- legislated entity?

Can the kind of coordination and cooperation that we're discussing here take place without that? Is the study that you've given to us here something that can happen without specific legislation to create an entity?

How is it best—or I might commit blasphemy here, I guess, and suggest a specific congressional committee dealing with oceans and the atmosphere, as a separate committee in the Congress.

How best do we proceed on this?

Admiral WATKINS. Well, I think the very fact that we have 47 committees in both houses of Congress dealing with the oceans, we have nine federal agencies who came up their own routes knowing that the oceans were important to their missions, tells us that we have the right debate going on here this morning.

And I believe there are things that we can do right now. We don't need legislation for you all to hold an annual hearing, by joint committees of Congress.

What we're trying to do is say, don't let it go. Don't let it go again for 25 years, as we have before. Let's put what we're practicing today into being and let's say that we agree that there should be an ocean partnership act and that the Congress will be a member of that partnership.

We cannot do it alone. You can't chastise the Executive Branch for not coming together if the Congress doesn't come together because if you pull out Mission to Planet Earth funding, for example, for NASA, we all get impacted. It isn't just NASA. It's the rest of us.

If we don't give the right amount to the National Science Foundation to do the kind of extramural research, it won't get done.

And so, we can do these things without legislation that I'm talking about. I believe legislation is important to get the visibility and to encourage your Senate counterpart to do the same thing.

When we had the Joint Committee on Atomic Energy, we had a body of people for years who up in the Congress knew what they were talking about on things atomic. They really did—the Jacksons and those people were terrific. And the chairmen of the committees over here that were members of that joint committee, they were powerful and they moved things.

So if we want to move something, then at least at some point the kind of notables that you have up here today, the top agency heads coming before you and talking about it in broad terms is critically important as those 47 subcommittees—appropriations and authorizations and so forth—review those individual programs, and we ought to star those things that are cross-cutting.

And please don't take them out over in one committee to save a dollar when, in fact, you impact on all nine of us, and the academic institutions in the process.

So I believe that—I don't know about the aquatic institute. I haven't reviewed that. I don't really understand it yet. I'd have to understand that. But I believe there are things we need to do now while weighing the debate on that kind of an approach, the NIH equivalent, if you will. That could come a little later, I think, and it needs a lot of thought and a lot of addressing on how that would work.

I just haven't reviewed that proposed legislation.

I think what we're talking about is something in FY '96 to prepare for the FY '97 budget, where we can say to you, we need certain access to data that we share, all nine agencies share, and the academic institutions contribute to and the private sector needs.

We have needs in the area of people and education that are cross-cutting across all these things. We need people in marine policy. We can't throw away our master's degree in oceanography as we do today. We need them in industry.

So we need your help in just a simple way. If you'll just agree to do this once a year, you'll go a long way.

Mr. GILCHRIST. I think we want to agree to do this once a year. I think we're touching on maybe the heart of the problem and Dr. Frosch touched on it a little bit before, about we have all this science out here and we have all of this knowledge. We have all of this expertise here.

And if we said this was going to be a hearing on Whitewater or the travel office, the place would be filled with reporters and filled with cameras. And yet, that has absolutely nothing to do with the survival of the planet.

And here we have one of the most important topics that we can even discuss, and you don't even see a lot of members here.

Dr. Frosch made a comment about you have all of this science. How do you get it to the planning and zoning commissioner of a particular town that lives on the coast so he doesn't have construction take place on a critical spawning area for certain kinds of fish?

They don't ever get.

I had a lot of questions, too, and I want to make a comment about how NOAA and the Navy coordinates their activities with their fleet and how important the NOAA fleet is with the naval vessels that are doing similar research.

But I think what is critical for us here, and I think you've hit the nail on the head, we don't need a lot more legislation that's going to get lost in the archives of the Library of Congress. But our stress has to be on the critical nature of the value of the oceans to the quality of life.

We just don't want to survive as human beings on the planet. We want to have some sense of living.

And Dr. Ballard made a comment about it's great to go into space, and I think we should continue to go into space. But we on the earth, even with the oceans, to a large degree, have no more frontiers. We can't expand into what Lewis and Clark explored. Our last frontier is our intellectual battle to survive.

I don't mean to go into—I apologize for this platform here.

[Laughter.]

So I think it's critical for us to maybe continue to correspond on a regular basis with each of you so that the next time we do this, if we're all here next year, or whoever is here, that we can get this thing so prepared and have some sense of depth of the dimension of the problem that we're talking about so this place will not only be filled with your staff, but it will be filled with people wanting to know more about what the problem is.

And we have to create, it seems to me, an entity that can focus on that. If it's too watered down—you know, the reality of the guy, the county commissioner or the mayor or the planning and zoning fellow is that there's a lot of them. They don't quite get the information. They have a lot of problems. They're focusing on taxes. They're focusing on snow removal. They're focusing on sewage. They're focusing on their bad marriage. All these things.

We've got to focus. We have to have some entity, it seems to me, in Congress that can on a regular basis—and these hearings in these other areas need to take place. But the reality of this place, unless there's a powerful focus that can shake loose some of the dust, not much happens.

And I apologize, Mr. Chairman, for that. I'll have to send my questions to these gentlemen.

[Laughter.]

Mr. WELDON. No, your points are well made, and that's the basic problem we're trying to deal with, is bringing it together to provide that new focus. And I think it's up to each of us to make it happen.

You've got assembled here an historic panel that I don't know has ever been assembled before, at least in recent times. Now it's up to us to play our role in the Congress.

I look around the Science Committee room here, which I'm a member of. I don't see anything relative to the oceans. I see a lot of outer space models and things about what we're doing in outer space. I don't see anything talking about—I don't see a model of our undersea activity.

It's our own I think effort that we've got to try to change in the Congress.

So I think looking for answers outside of the Congress is part of the problem. But I think looking within the Congress is the major problem.

If we get together and push this issue, we can make it happen. We've done that in a number of issues. With people like you and the other members here, I'm optimistic that we'll be successful.

Did you want to respond, anyone, to Mr. Gilchrist's comments? Dr. Frosh, and then Dr. Alberts.

Dr. FROSCH. I only wanted to reinforce the comment that the ability of the federal agencies to cooperate and work together on a problem that covers all of them, or many of them, is a reflection of the ability of the Congress to give them authorization and guidance in a way which is comprehensive across the problem.

That may require an institution or it may require some special handling. But the difficulty has frequently been that each agency gets its direction and instructions from a different committee and a different subcommittee for which there is no mechanism of coordination.

So they get separate instructions and when they try to coordinate, they sometimes run into real difficulty.

I think this is a very important point.

Mr. WELDON. Good point. Dr. Alberts?

Dr. ALBERTS. I just want to make the point—I don't want to comment specifically on the new national institute, but I don't think this can be done only by government.

Part of the message here is we need to get the user community, people in academia who are experts, people in private industry, to be an important part of this process.

I think that's the way you get people to cooperate. You need some outside—both the information they bring and the pressure they put on are sort of inertial mechanisms in government to make things change.

So I think, no matter what kind of government structures you need, you need these partnerships with the private sector and with academic institutions to be stronger and to be informing this process.

With regard to the issue of the person on the coast who needs the information, I think we have a brand new tool we should be thinking much more seriously about, and that's, of course, the World Wide Web.

We now use it for E-mail and there's a lot of junk on there. But we have to think as a community about setting up specific platforms which will be useful to those very people you're talking about which will connect them.

We have the opportunity now to connect them to information and to people directly in ways we never have been able to do before.

I think the scientific community in general has to work with all of the agencies to try to think through this and how can we get this information accessible to the whole country and everybody who pays for it and everybody who needs it.

And conversely, how can we feed their ideas through the same mechanisms to government about things that they need?

We have a great way of communicating that we haven't even begun to exploit.

Mr. WELDON. Thank you for your comments.

I think, along that line, in terms of provoking the private sector, I would agree with you totally.

I can recall in the ten years I've been in this city that we've seen a number of shows and demonstrations of technology relative to outer space in the Cannon Caucus Room and the Capitol. I don't remember any really kind of public demonstration of what we've done in terms of the oceans.

Maybe we've got to get a couple of members of Congress to go down in ALVIN or in one of the undersea research vessels. And some might argue that we should leave them there. But——

[Laughter.]

Mr. WELDON. I would not go that far.

[Laughter.]

Mr. WELDON. But I think we've got to do more to promote in a very visible way what you're all doing and perhaps take for granted. But we deal in perceptions here and the perception has not been raised yet on the issue of ocean research perhaps to the level it should be.

I'm taking time, so I'll now defer to my good friend and colleague, Mr. Bateman.

Mr. BATEMAN. Thank you, Mr. Chairman, and a very special thanks to the panel. You've done, I think, a very, very constructive job in helping us focus on something that is of vital national concern and something that the Congress needs to truly do a better job of focusing on.

Dr. Baker, I want to paraphrase, if I may, Daniel Webster. It's a small program, but there are those who love it. I'm referring to the oyster disease research program, which wasn't included for funding in the FY '96 budget.

It is a program of very, very significant importance to not only the problem of the world food supply, bearing in mind that oyster production in the Chesapeake Bay and its tributaries has declined by 200, 300 percent, and seems to still be going down.

There was and is an ongoing oyster disease research program that focuses on dermo and MSX and the other diseases to which the oysters have been preyed upon.

I would hope that the FY '97 budget would recognize the importance of this program and that there would be a plan of continued support for oyster disease research through the Sea Grant Program or any other programs.

It is just too important, not just in terms of long-range food supply, but certainly in terms of the economies of the people who have harvested those oysters, who have packed and processed and marketed them.

It really represents severe economic distress to these people. The oyster disease research needs to be continued and is showing promise.

So I hope that NOAA will focus upon that and find the capability to continue planned funding for it in FY '97.

I appreciate the fact that we have a common enemy of all good programs and that's the Office of Management and Budget. But within your constraints, I hope you will see fit to support it.

Another thing I'd like to comment on is back in the late '80s, there was a concern in the old Merchant Marine and Fisheries Committee, of which I was a member, about the NOAA research fleet and the need to modernize and upgrade it. And in 1990, we passed a NOAA fleet modernization act, after a report from NOAA.

We don't seem to have gotten very far on that. One of the things that we mandated was a NOAA study and program for the modernization of the NOAA fleet.

We got the report. We got the study, but not on your watch, but your predecessor's. It never even got included in any budget submission.

You made reference in your earlier statement that you do have a revised, updated program. I hope that program is one which we will see evidences of and support for in your budget submissions and that we'll be in a position to help you make those things happen.

Dr. BAKER. Thank you, Congressman Bateman. I will look at the oyster disease program. That has been an important program. It's one that we will certainly be looking at in the FY '97 budget process.

On the fleet modernization program, as you know, there was a program that was put together earlier by NOAA. The cost of that program was about $2 billion. It was my view, and I was encouraged in this view by many members of Congress, that that was probably too expensive for us to handle in the current budget context.

We currently have a plan that is less than half of that. It still costs money to replace ships, however you do it, whether you buy new ones or you contract out. But less than half of that cost.

And as I said, it gives us a mixture of in-house, private-sector, and academia, and it allows us to look at the cheapest alternatives of each way we go.

We're working that through OMB at the moment. Once we have approval, you'll be seeing that. We have been able to brief staff on some of the details of it and we'll keep you informed.

Mr. WELDON. Thank you, Mr. Bateman.

Our next questioner, Mr. Kennedy.

Mr. KENNEDY. Thank you, Mr. Chairman.

I just want to echo what's been said a couple of times here in different ways. And that is, I think the problem for the public in embracing the importance of this issue is that the knowledge is so diffuse and its impact is so real. But we have yet to be able to target it and be able to answer some very specific questions.

Now, when I was asking Dean Lynon from the University of Rhode Island School of Oceanography the other day, why can't the scientists and academicians come up with a way of hitting us between the eyes with the significance of the oceans and the survival of the planet and both measuring global warming and identifying the fact that, with the growing population, as Dr. Ballard was saying, the reliance on seafood is going to grow, and the availability of our natural resources to sustain an adequate supply of seafood is going to diminish correspondingly as the population grows.

What are we going to do to manage all of these resources that are becoming so finite and precious?

We need to be able to have predictions and predictive models that unless we do X, Y is going to happen. And the difficulty with science is that everything has to be down to the—the correlation has to be so specific. As Dr. Ballard was saying, some of these cycles with fish populations are natural, some of them are man-made.

We need to be able to distinguish the difference between the two so we know what part of it we contribute to.

So I think, with all that is being said, hopefully, with this new clearinghouse, and I fully support the concept that's been outlined by Admiral Watkins in terms of the ocean partnership act, we'll hopefully be able to cull all this scientific data and make some predictions.

Because unless we do that, the political capital that's going to be able to be leveraged to support initiatives that we're talking about here is not going to be here.

It's already been testified to, that fact, today in the hearing. If it weren't for the Navy and the necessity of the Navy to test acoustics and sonar rays and to be able to research the oceanographic and the seabed because of the threat of nuclear submarines and so forth, a lot of this research wouldn't happen.

And to answer Congressman Roemer's question about how are we going to drive this, fortunately or unfortunately, a lot of it is going to be driven most directly by our national security.

And that's where I'm encouraged by the fact that now our challenge in the littoral warfare environment is the coastal zone. It's the exact area that we need to focus most on, environmentally.

So if it has to be the Navy that fields the unmanned underwater vehicles or the kinds of tools that allow us to cull this science, so be it. But we've learned here today that that research that the Navy undertakes has a broad range of applicability to the broader environment. And vice versa.

So I think what we've heard today is a beautiful explanation from all the panelists about the need for this Ocean Partnership Act because if the Navy diminishes its research in one area, obviously, it's playing that shell game.

Just two years ago, the Congress had the big debate on our health care industry. There was a lot of talk about global budgeting.

Well, if there's ever an area where this shell game will be a law of diminishing returns if it's not put into this global budgeting, it's this area of the environment. How do we take all this science and make it help itself in an interdependent way?

So I would like the panelists to comment on maybe the law of the sea because that's now something that's relevant in discussing the need for us not only to cull all our resources on a national basis within our own country, but also internationally, how they see the law of the sea figuring in this discussion that we're having.

If I could turn it back to the panelists.

Mr. WELDON. Whoever would like to respond—Admiral Boorda and then Dr. Alberts.

Admiral BOORDA. For the military, you could not have found a more complex question to ask when you began to ask about law of the sea.

Mr. KENNEDY. I heard myself starting to sound like Congressman Gilchrist. Both of us have a lot we want to say, as well as the Chairman, and we get off on our own tangents.

Admiral BOORDA. We have a lot of lawyers in the Department of Defense and the Department of State. I have two in my family and that's not even enough to solve this problem.

It is basically interpretations of what that law means in the private sector. But in the military sector, under the current conventions and under the law of the sea, we have some freedoms that we don't want to lose, where we may operate—and it's different with different countries. It's different in different places. It is very complex, depending on how you draw baselines and other things.

The one thing we want to be sure of in defense is that we don't lose the prerogatives and the abilities that we have because to work off those 240 ship-years requires that we continue to have the ability to get where we need to get with, and sometimes without, the permission of coastal states.

So it is a difficult problem.

There is some work under the law of the sea and under current law that only we can do. And so we need to be sure that we are the ones that are doing it.

When a university tries to do it, when NOAA would try to do it or someone else, it would not be possible. And I don't see that changing.

We are, and I think it's somewhat related to your question, we are upgrading other agencies, other people, to be able to do the work that they can do. We're trying to help with that so that we don't have to do it all.

For example, we've delivered six new ships to universities in the not too distant past. As we've downsized our Navy in some of the things we do, some of the shipbuilding that was pretty far along in these kinds of ships have been turned over to people who can do good work in areas that Mr. Kennedy is talking about. And we obviously don't want to work off our coasts right now. We have other places to work.

So I think you're on to something. I think we need to be very careful about exactly who does what because there are some things that only some of us can do.

I would not, for example, want to work in bays and in coastal waters of the United States. There's absolutely no reason for me to do that, and it would use up resources that I can use better with these overseas-deployed eight ships.

So it is extremely complex, that's my point. And we have to coordinate what we do and we have to get coordinated guidance back from you so we can do it.

Mr. KENNEDY. Thank you. Dr. Alberts?

Dr. ALBERTS. Mr. Kennedy was pleading for science and scientists to get together and provide interpretations of what science means for people like you and what it means for our nation.

I should remind you that the National Academy of Sciences was chartered by President Abraham Lincoln to do exactly that. We do it with 6000 volunteers, scientists and other people working at any one time.

More specifically relevant to your point is that last year we saw it was important enough to deal with this issue of sustainable marine fisheries world-wide, to take nearly half a million dollars of our own endowment funds and investment in a major study that we expect to be completed this August on providing you the kind of advice that you're asking for on the fisheries issue.

And so I'm looking forward to providing that to you late this summer.

Mr. KENNEDY. Thank you. I look forward to receiving that.

Dr. Ballard?

Dr. BALLARD. Relative to the law of the sea and from a perspective that probably you're not even thinking about, but in my testimony, I made mention to how our exploration in the deep sea is discovering a tremendous amount of human history that is preserved in a state of high preservation, much more preserved than one could imagine.

When we went to Guadalcanal, for example, and found the warships of that great historic battle, they still have their camouflage paint. And when we found the BISMARCK, it still has the swastika on the bow.

One of the problems you have is there's absolutely no law right now to protect ancient history beyond 12 miles, which is most of the world.

And so, one of the concerns I have, as you know, when we found the TITANIC, we tried to protect it. We came to the Congress. The Congress and the Senate passed the TITANIC Memorial Act of 1986, which President Reagan signed into law.

It had absolutely no effect on preserving that ship from other countries that went out and then completely tore it apart, and are continuing to tear it apart.

The only way we can protect historic sites, this summer, working with the Navy, we discovered a Roman fleet in the high seas. There's absolutely no protection of that archeological site, other than to not tell anyone about it, which is quite a difficult thing for a scientist to not be able to publish their result.

So I would encourage you to have an ear for future legislation that deals with the law of the sea as it relates to human history as well as natural resources, because I can tell you that it's an incredible amount of history, more so than I ever imagined.

Mr. KENNEDY. I just want to add, on the economic interests involved here, you have one-fourth of the world's oil production offshore. You have one-fifth of the world's protein come from foodstuff.

So if you're looking at food and you're looking at energy, these are two major commodities that the world populations can depend on. If you don't have a means to resolve a conflict of those economic interests through an international law of the seas, that's where I think we're really going to need to—and when I'm talking about getting scientists to understand how they interrelate, it's precisely for the reason that was mentioned by one of my colleagues in terms of being able to elucidate it so it can be useful as a management tool to local planners, so that we understand what the impact of one decision is on another.

In Rhode Island, we had the worst air quality standards in the nation. A large part of it was because the wind was blowing up from some of my colleagues' states down south of us.

[Laughter.]

It's a perfect example. We need to know the interrelation. We had to study the difference between stationary sources of pollution through factories and mobile sources through automobiles.

There is such a reliance on sharing information here, that we can't be doing these things in a vacuum, which is the whole reason we're discussing this, is how do we bring everyone into the same fold.

So, again, I think Admiral Watkins' proposal of bringing this together in a holistic way is something I support and I look forward to supporting, Admiral, as one member up here, and I know my colleagues on the panel will look forward to joining to do that as well.

Mr. WELDON. Mr. Kennedy, what state were you referring to?

[Laughter.]

Mr. KENNEDY. I won't say right now. I beg your indulgence.

[Laughter.]

Mr. WELDON. Ms. Johnson is not here. Mr. Meehan?

Mr. Taylor?

Mr. TAYLOR. Thank you, Mr. Chairman. I want to thank the panel for their patience today. Above all, I want to thank my constituent, Admiral Gaffney, for coming up today.

My question is not just directed to your community, but what I see in the science, the government-sponsored science community in general.

And that is a great deal of research that has private-sector uses and applicability. Somehow, the word just isn't passed to the private sector.

And in the case of some of the things you've told me today, I think it's really ironic that I can get a surplus Navy 671 engine or a hatch or an anchorchain, advertised throughout the country in "Boats and Harbors" and other publications. But some of the great research you've done like showing the correlation between thermal climes and fish populations——

Down at the NOAA station at the Stennis Space Center, for example, they can pinpoint the ten most likely places to catch tuna on any given day, by taking NOAA's research together with remote sensing from satellites and correlating the two.

I'm sure that's just one of a thousand things that you have discovered that somehow just isn't marketed. And since we are in an age of budget-tightening where, especially with the gentleman to my left running things, they're a business-oriented group. There's nothing wrong with that. That's good.

My question is how, without jeopardizing national defense, can you make some of these things that you have found available to the private sector so that the American citizens can get some sort of return on them?

And what would be your means of marketing this, or at least letting people know it's available?

Dr. BAKER. Let me comment on that because I think that's a very important point, Congressman Taylor. And something that we have been concerned about in this Administration is about how we can use that kind of information and how you can make that transfer, because there is a lot of valuable information. But how do you make the transfer and still preserve national security, is really the issue?

One of the things that the Vice President did was to continue to encourage this group of scientists who have all the clearances to look at the systems, and this is DOD scientists and civil scientists from NOAA, National Science Foundation, and the academic community, to look at those data sets and say, are there some that in fact might be released, or is there some information in those data sets that might be released that could be of value to the academic community and to private industry because once it gets out there, they're going to use it?

We're in the process now of doing some experiments to find out whether that really can be done. I think this is a very productive activity.

I held up this Popular Science before because I was talking about the Navy's GEOSAT program that had been released. But the cover picture is actually the first step on releasing some of the classified data from spy satellites that was done from 1960 to 1972, a good start on information that is in the intelligence archives and in fact can be made available.

So I think we have a process in place. We're doing it very deliberately because it's absolutely essential that the national security interest be preserved.

At the same time, there's an interest from both the DOD and the intelligence community to try make this work.

So I think we're making progress.

Mr. TAYLOR. May I interrupt for just one second?

It came close to home. There's a project to try to get some fresh water from the Mississippi River into the Mississippi Sound to get the proper mix of salinity and fresh water to produce oysters, amongst other things.

I really found it strange that the Corps of Engineers went out and contracted someone to drop something like 5000 small balls into the water there so that they could map the flow of the water through Lake Pontchartrain into the Mississippi Sound, when Admiral Gaffney's crew, using remote sensing from satellites and just the difference in temperatures, could have done it sitting at their desks.

How can we as a Congress expedite getting people to talk to each other in the different various government agencies?

And again, I'm sure that's just one very small example of what's going on every day.

Admiral BOORDA. It's probably a very good example. I don't know about it, but Paul can talk about it in a minute if he wants to.

Let me tell you that it's getting better. It's not fixed. I don't know about a lot of balls in the river. But what I do know, because we don't work in the river. We work out away from the United States. That's our charter.

But we had, and I think it's really what we're looking at in this Popular Science, we had the GEOSAT satellite in the '80s. In July, as a result of us all getting together, we released all that data, declassified it, for scientists, for these agencies, for business, for anybody who needs it.

We're going to launch a GEOSAT follow-on satellite, GFO, this next year. In fact, it will be this spring. And that might be something we can use as an interest-getter that you talk about. I have a couple other things and I'll fold them into this answer.

I don't know how I'll fit it, but I'll make it work.

But that, with a five- to eight-year life expectancy, will do the following things, and probably lots more, but directly related to what you're talking about.

It is the same as dropping millions of bathythermograph devices that tell us about temperature and the thermoclime and lots of other things, every day.

Having that one satellite for five day-years will give us the same data as if we dropped millions of those every day. That's important.

It is the same as having fleets of ships sailing the oceans of the world and reporting every day wave heights every 20 kilometers. We have to focus where we want to look.

All this data, already decided before we do it, all this data is going to be unclassified and go to the public.

Mr. TAYLOR. My question, then, and Mr. Chairman, this will be my last question, how do you get that information to the public, Admiral?

I know where to buy a surplus Navy anchor. Where does an average businessman who's looking for an opportunity in the next century go to get that information?

Admiral BOORDA. I don't have the answer. Paul, can you help?

Admiral GAFFNEY. I'll try.

Admiral BOORDA. Before you do that, let me just make a couple of offers here, though, because I'm not going to get another chance, I don't think.

In Congressman Taylor's district, we build those ships I talked about, those survey ships. This summer, two of them will be finished and deployed overseas. They won't be back. We don't make any progress in our work by having them back and forth from the United States. So they stay over there and we change out the crews, civilian crews.

I will make that information available to the chairmen of all three subcommittees and there is no reason for people not to go down there and get on those ships and go to sea and see what they can do and report it back to their constituents and to the Congress.

Mr. TAYLOR. Admiral, you might remind them that Mardi Gras is less than a month away.

Admiral BOORDA. No, sir, we don't do that in the Navy.

[Laughter.]

Mr. TAYLOR. The opening of shrimp season in May.

[Laughter.]

Admiral BOORDA. I have two other things I want to mention.

We have an ice camp this year in the Arctic. Admiral Watkins knows a lot about that. He and I went there together in the April/May timeframe.

Anybody that would like to go on this panel with me I will take. And we'll go up to the Arctic. That is a scientific expedition. Next year we'll do it again in something called the Spinaker Program in the spring.

We have to take cameras that really don't have too much oil in them because it freezes. But we can do that on a weekend, believe it or not. So we leave on a Friday night, go to the North Pole, and be back in time to go to work Monday.

Mr. WELDON. Admiral, if you will give us descriptions of each of those, we'll get them to all the members and see if we can get some member interest in one or more of those activities because they're excellent suggestions. (See Appendix II, page 195 for information supplied by Admiral Boorda.)

Admiral BOORDA. Yes, sir. Let me turn it over to Paul with the specifics on the answer to that.

Admiral GAFFNEY. Mr. Taylor, I think that your charge is really going to be a major issue and a major goal for Admiral Watkins with his National Ocean Leadership Council, is to figure out how to market this information that we have. It's got to be a primary goal of that coalescing of this group in a more formal way.

I will mention that, as was mentioned earlier today, the World Wide Web is going to be part of the solution. Everybody here is on it. There's a move by the Office of Naval Research to re-establish a bulletin board system that links oceanographers together.

We have just in your district in the last couple of months, the home page for the Naval Oceanographic Office has had 11,000 queries. We count every query that comes in.

So the word is getting out.

The MEDEA group that we talked about before, a number of cleared scientists, several of those people are from industry as well and they are getting to see exactly what we do.

So the word is getting out to them, to the oil industry and to other folks that are interested in our kind of information.

And I think an important point and something I mentioned in the testimony is we need to infect the young folks in this country with our capabilities and with our challenges so that they on their own will be interested in coming and finding out what's going on.

We need that because we need their talent in the future. We want to infect them.

So we have a little bit of a responsibility to education. Thereby, getting on the Internet, the World Wide Web and getting our word out is our responsibility to help do that.

Dr. BALLARD. I think picking up on that same note, I think there's no excuse now, given the development of the information highway and the distribution of information for people not to be able to get information.

I encourage all of the members here of the panel to not only look at the distribution of data to specific organizations or specific institutions, but to the public at large.

There is a proliferation of media organizations that are attempting to present information to the public in digestible fashion, to the lay public. Certainly, I work a lot, for example, with the Navy and with CHINFO to be able to do programming that can be presented to the lay public through National Geographic or NOVA or other forms of presentations.

There's a tremendous opportunity that is emerging with the telecommunication industry to present oceanographic information to everybody in this country. I just would encourage my fellow panel members to think about how they would not only present it to their peers, but how would they present it to the farmer in Kansas or to the school child in Mississippi.

And those opportunities are now here. It's a question of whether the scientific community, the military, or the agencies are willing to take the step to translate it into things that the average person can understand.

Mr. WELDON. Dr. Frosch?

Dr. FROSCH. I only wanted to comment that making the basic data and information available is only the first step. That will not necessarily produce a good prediction for a tuna fisherman.

One would hope that when the data is available and there's clearly a market for specific forecasts and information, that there will be some entrepreneurial activity, and as has happened in other such information areas, there will be businesses put together to take the information and provide forecasts and details for the market that will use them.

But that will only happen when the information is really available and it's clear it's going to go on being available to create such a business.

Mr. WELDON. Mr. Kennedy?

Mr. KENNEDY. Yes. Mr. Chairman, I just wanted—in Rhode Island, we have an ocean technology center which does much of what I think my colleague was interested in doing.

I'd be happy to get more information about that to any of my other colleagues.

Mr. WELDON. Thank you, and thank you, Mr. Taylor.

Our next questioner is the distinguished gentleman from California representing Monterey Bay, who I understand had a leadership role in his state in ocean research management.

So we're very pleased that Mr. Farr has been here with us.

Mr. FARR. Thank you very much, Mr. Chairman. I spent 21 years doing coastal zone management issues and I've been looking forward to this day my entire life, I think.

I hope that you'll follow up on creating a task force and I pledge all the energy I have in Congress to make it work.

I would just like to comment that I think that this issue is more important than space. We need to make the world know that. I think that, also, we need to realize that all access to the ocean comes from the land. And as others have said, we need to elaborate a more vertical integration between federal activities and state and local activities.

In the State of California, while in the legislature, I authored an act called CORMA—California Ocean Resources Management Act. Governor Wilson has just released this report by the Secretary of Resources on California's ocean resources, pointing out that in California, it's a $17 billion industry, and equal in importance to the state as agriculture. And California is the leading agricultural state in the nation.

The governance is very interesting because we don't address those very often. But in addition to the multiplicity of land jurisdictions, you have complexities in our federal jurisdictions, with the Outer Continental Shelf Lands Act. We don't even know where the Outer Continental Shelf boundary exactly is and it's not well defined.

The Coastal Zone Management Act, which can go inland as well as out to sea, and how far out hasn't been defined yet. The Magnuson Fisheries Conservation Management Act. The National Environmental Policy Act. And certainly that of the EEZ, and the zone territorial sea out to 200 miles.

What our group in California, which is about 18 different entities, state and local, came up with is a whole bunch of chapters, but one on ocean research.

They made recommendations that I'd like to ask the panel about. One is they said that we really need to have a lot more collaborative work in making inventory of current and recent ocean and coastal research.

We need online computer services of a central directory of ocean educational programs.

We need to develop in our academic universities ocean policy programs.

And we need to invest more money in research, not just limited to the Sea Grant Program, which helps our state universities.

And I'd like to really ask Admiral Watkins, because I really thought your comments were—in politics, we like to say, I'd like to associate myself with that gentleman's comments. After you spoke, I just wanted to say, amen. You were right.

What my question is is how much of this collaborative effort is still locked up in classified research that should be shared more with academia and with our—we're using—all of the parties at the table are active on Monterey Bay. We have the Navy. We have the University of California. We have Stanford University. We have David Packard's Deep Ocean Research Center. We have NOAA. We have the Fleet Numerical Center that you talked about.

And the best thing about it is that they're all collaborating there on Monterey Bay and they're turning that collaboration into products for the private sector. But more importantly, they're turning it into products for elementary school children that are now communicating with ocean scientists about weather every day. In the third grade, they've got direct access to the NOAA weather satellite.

So it's so exciting and so much opportunity because, indeed, I think the answers for the problems of mankind on land as the population of this world doubles are going to be found in the ocean, our foodstuffs, our energy sources, and certainly our medical answers I think to a lot of biomedicine.

But a lot of that data is still in somebody's file. How do we get it out of there?

Admiral WATKINS. Well, I think one of the initiatives that we have going in the inter-agency partnership work over the past two years was identified in some of the testimony given by the panelists here this morning.

The NAVOCEANO people down at Bay St. Louis or down at Stennis Space Center, in follow-up to the Environmental Task Force work, focused specifically on the ocean data. And they've identified in a report, and we've provided that to the members up here for this hearing, this MEDEA report.

It goes into scientific utility of naval environmental data. This was put together by very knowledgeable people who are cleared into the highly classified areas and they're very sensitive to national security.

They've identified areas that are critically important to researchers. They don't particularly focus on the integrated undersea surveillance system, the component of which is most important to them would be the SOSUS network, the fixed-array network.

That's a ticklish area. The CNO is working very hard to take a hard look at that to see what can be really extracted or can be sanitized and made available.

That is critically important.

They don't have the money to keep all these arrays alive. We work with them—NOAA triggered off an issue with the Secretary of Defense last year and we were very much involved with our academic institutions to come together and say, what do you really need the information for from the fixed arrays that have gone after Russian submarines all these years? Isn't that valuable?

Well, of course it's valuable—for seismic projections, for fisheries tracking, for a whole host of things that we don't even know about yet, for acoustic thermometry of the oceans.

How do we really measure what is happening in global temperature?

Well, the greatest heat source in the world is the ocean. And if we can monitor that and get it down to within two-tenths of a degree Centigrade, we can really talk about global warming and what it's doing and whether man is doing this or whether nature is doing it in a much clearer way.

So that's just one network alone. It's tremendously valuable. It's a $16 billion investment. And that information needs to be moved.

The CNO has to get into the act himself. If it doesn't, the bureaucratic system will give it a 30-year period. I don't think it has to be that way with modern technology. We need to look at this much more rapidly than we have in the past.

When I was CNO ten years ago, we could look at things at a slower pace. We can't any more because technology outruns us. And much of the information we're now classifying, in my opinion, has been in the open literature for years elsewhere.

Right today, for example, we're what we call dithering the GPS satellite. That means we're sending out information that only certain receivers can receive.

Well, do we need to do that right now? Is the world threat such that we can't allow that data to go out?

I believe it can go out.

Mr. FARR. Is that an administrative decision or is that one that needs congressional authorization?

Admiral WATKINS. I don't know. I don't want to get into Secretary Perry's business because it may be a very valid reason. It's not clear to any of our researchers that you have to do that because there are alternatives means to get that kind of position accuracy that we desperately need to do the kind of work we need, precision scientific work.

So I think we're way behind the power curve on trying to modernize our way to declassify information that's already out there because of modern technology leaps in the private sector, where satellites today are giving the kind of imagery that allowed the CNO to downgrade the GEOSAT data of earlier years.

So I think we've got a lot to do there. And I really do believe that the Department of Defense has not been as aggressive as I think they could have been under the Environmental Task Force.

Whether it's politically driven, whether there are real issues out there, I don't know. But I do know that the DCI took it seriously, moved rapidly, and was able to downgrade satellite information very rapidly, much as the CNO has just done recently on GEOSAT data.

It's very valuable to researchers.

So I think it's an important issue for the National Security Subcommittee here, members of the National Security Subcommittee, to focus on in their full committee hearings. And let's get serious about doing it in a more accelerated way because we can cut costs tremendously. We don't even know the value. But we know in just that MEDEA report for Navy data or environmental data alone, there is tremendous excitement in the research community that if we can get this data, we can do research faster, better, and we can avoid the kind of costs where we're now going out individually and trying to find the alternate systems.

Mr. FARR. Mr. Chairman, this is key. This is without having to spend any more money. This is taking existing data and existing facilities and using them more collaboratively.

Admiral WATKINS. But in all fairness to the Navy, I think that we did have reason prior to the demise of the Evil Empire to protect a lot of that data that I think now, with a good hard look by technologists who really understand these systems and what alternatives are available to the Ghadaffis and Rhafsanjanis and the North Koreans of the world, we can still protect ourselves and do the job better.

And I think this is one of the areas where our collaboration has focused and our report, our report that we just came out with, focuses on this as one of the key areas on declassification, and do it sensibly, but do it more in an institutional process with the Congress involved in this, with intelligence joint committees, whatever is necessary.

But move expeditiously. We've really got some leaps to make here right now and we're not moving fast enough.

Mr. FARR. Mr. Chairman, just an anecdote.

The Monterey Bay, which has this big submarine canyon. It's as big as a Grand Canyon. It goes down 12,000 feet and about 270 miles long. It's a mile offshore.

DOD contracted with the academic community to map it locally. That information was classified. So when David Packard opened up his Deep Ocean Research Center, the former Undersecretary of Defense, he couldn't get access to the information about mapping the canyon. He had to go through a real lengthy process back here to get it all declassified.

It was essentially data that everybody there in the marine science community needed to have. Now we've got maps out and we're selling them to the public.

But that kind of classification of that material was just ridiculously private, I thought, in our military, in a sense. So I appreciate that.

And lastly, Dr. Baker, you closed the office in Monterey that was translating all that data into the private sector. How are we going to do this dual-use if those types of offices, the ocean branches, the ocean research branches, close?

Dr. BAKER. Well, Congressman Farr, I think that's a good example of the real tough choices that we have today, with trying to solve problems and to do it in a real tough budget climate.

We are hoping that we can carry out that activity and still provide the information that was being developed out to the public.

All of the NOAA information is provided on the World Wide Web. We are using, as has been suggested here, we are already doing that. We're using all of the technologies to get information out to the public. And we're working very hard to make sure that the information that that office was providing is still available, although in a slightly different form.

And let me say also, we are making sure that the Sea Grant Program is adequately supported so it can can carry out its extension and education programs because the Sea Grant Program, as a link to the public, is absolutely critical.

Let me just say one other thing about our activities in Monterey, which are very collaborative with the Navy, with the state agencies. You've been a big help to us in helping us organize that.

We've been working with the California Coastal Commission to look at the Monterey Bay watershed to understand the impacts of land-based pollutants on the bay. We have a group that is out there now under Bud Ehler and our National Ocean Service so that we can understand what the impacts of land-based pollutants are in Monterey Bay before the bay has a problem.

And if we can put those things in place, that's a way to make it work.

And I think this is a very good example, of your suggestion about having a federal/state/local cooperative activity that really helps us make sure that we can sustain economic development.

Mr. FARR. Thank you, Mr. Chairman. I hope you invite this whole committee out there just so we can have a follow-up with the panelists and really see what it's like to apply all of it in a collaborative way.

Thank you.

Mr. WELDON. Thank you, Mr. Farr. Actually, in line with your suggestion, we've already committed to a West Coast briefing like we had in Rhode Island on Monday. We're in the process now of getting a date and a site, but it will be specifically to continue the work that we've started here.

So that commitment has already been made.

With that, we'll move on to Mr. Olver.

Mr. OLVER. Thank you, Mr. Chairman.

I wonder if you'll get more people for the West Coast survey or for the ice North Pole on this spring which the Admiral had suggested would be available to us.

[Laughter.]

I think it would be interesting to go back to something, Mr. Chairman, that you had said about the sterility of this room. And it certainly is sterile. There is nothing to keep one from going to sleep sometimes, at least on the walls here.

It would be interesting to see whether the people who are here, out of all of this data we are now being told is classified, and that shouldn't be classified or doesn't need to be classified.

And by way, to my colleague from California, I would just like to say, amen, again, because every time Admiral Watkins opens his mouth, it seems to me that a good deal of wisdom seems to come out.

The last set of things just added to that, the whole set of comments about declassified data.

But it would be an interesting test to see what kind of declassified data we could get that would fill that wall over there with the best ocean floor mapping data that is available at the present time from classified or declassified information.

And I use the comment from classified or declassified information because I am absolutely fascinated by this set of conversations. And I missed the original testimony. Quite often you can read that if you ever have time.

But it's given me time—this is a diversion—given me time to look through this document and this document, which we were all given as background for the discussion. And Admiral Watkins, to take away slightly, you said that there are nine agencies. Well, there are five of those agencies that are listed here. There are five agencies listed in this MEDEA document.

I looked through this carefully. I cannot find for the life of me what MEDEA is.

[Laughter.]

(Clarification supplied by Admiral Boorda in Appendix II, page 196.)

But it suggested that there ought to be inter-agency collaboration among, in this instance, five agencies, not the same five agencies that are here. And you mentioned nine. So I'm still missing what the other three are because none of them are agencies which are here at the table. Except that I do know that NASA is not here at the table.

Admiral WATKINS. They're here in the room, though, Mr. Olver.

Mr. OLVER. Okay. I'm sure they are. They're also on the wall in the room.

[Laughter.]

But as a scientist, I get much of my science these days from a variety of magazines that come in. But also the popularized science section, say, of the New York Times that comes out every Monday or Tuesday, whichever it is.

Three months or so ago, there was this wonderful article to me, because I'm interested in geology although I was a chemist, about the seamapping done by NASA. I think it's been declassified. I believe it was data that was done in the late '70s or around 1980 or so, and they finally declassified it and made available a map, which I immediately bought from the University of California.

Now I don't know whether that's a SEASAT satellite or a GEOSAT satellite or what the hell satellite it is, but clearly there are several different people doing essentially the same thing.

That set of data, if I remember correctly—you may want to correct me because sometimes you get rather incomplete impressions from reading those, even though rather long, whole page New York Times with pictures and charts and so on and so forth, saying that they were able to map at contours, I think, if I remember correctly, two feet, but no greater than ten feet in mapping that was much more sensitive than what had been available by the old ocean floor mapping from a fleet.

Obviously, there are many different forms of that that are out there and obviously, we could have an extremely high sensitivity map on this wall which would probably keep everybody awake and maybe distract them completely from what was going on at the tables, which might not be such a bad idea sometimes.

I shouldn't say that because, really, the data that comes in and the information that you've put forward today is extremely fascinating, at least to me.

So data that would allow us to know some things about where tectonic plates are that are changes in the thinking, obviously, the scientific community knew that and I'll bet major portions of the scientific community knew it.

Why didn't everybody know it? There's no reason why it shouldn't have been available I think much earlier to anybody who might be interested in knowing where volcanic activity and sea mounts and other things at much greater discrimination than had been known before.

Maybe I'm exaggerating.

I suspect that they must—if that's true, they must have been able to see the TITANIC. We must have been able to see the TITANIC with some of these data. Or maybe it was in terrain that wouldn't permit that.

Dr. BALLARD. Unfortunately, it was in terrain that wouldn't permit that.

Mr. OLVER. Okay.

Admiral BOORDA. If I can respond to that just for a second.

What you're talking about is the GEOSAT data that we released in July.

Mr. OLVER. GEOSAT data.

Admiral BOORDA. And the map you're talking about is that one [indicating]. And of course it can be much more detailed and it's a real different view of the earth because the land part isn't the part of interest here. It's the oceans.

Mr. OLVER. Why did NASA take credit for it if GEOSAT was the Navy?

Admiral BOORDA. It's not important. You may be talking about something a little bit different. That's not my real point. That's gravity data. And why do we care about that?

Why do we care about that? Now we've declassified that. Why we care about that is because we want our strategic ballistic missiles to hit their targets, particularly the hardened targets which require a very tight circular error of probability.

We don't want their nuclear weapons to hit our targets with that circular error of probability. We need to be careful what we do. We were careful as the Cold War ended, as we looked at things, we released that data.

It's fun, I think, to talk about declassification and look back on times when people were extremely careful and cautious and sensitive, I think kind of words you'd like in different hearings. You might say you need to be extremely cautious, careful, and sensitive, Admiral. And in other hearings we might say, my God, just open it up.

What we need to do now, I think, is understand what we are much more open. That's what MEDEA is about.

We've got cleared scientists looking at these data sets, and we look at these data sets and together, we are deciding and recommending what we can do.

Mr. OLVER. Will you declassify for me what MEDEA is? There is no definition of what it is in this.

Admiral BOORDA. I'll let Admiral Watkins do that because he testifies so well.

Mr. OLVER. Yes.

Dr. BALLARD. Let me comment on that.

Mr. OLVER. Admiral Watkins certainly pointed out and defended you, while saying, declassify the stuff now. The Evil Empire is over, and so on. I suppose there are some of those things that one should still worry about. But, boy, there's a lot of duplicative data out there that different groups have been putting together that we really do need the cooperation and coordination to use what seems to be the watchword here this morning in a variety of different ways, in making this available to everybody and let's get on with it to avoid what the gentleman from Mississippi pointed out, or what you yourself pointed out about how those data and the sensitivity to taking those data, salinity and temperature data and those kinds of things that we could be using that it would take fleets and fleets to get out there and get that in the sort of more traditional ways.

Mr. WELDON. You've got a number of individuals who want to respond.

So why don't we start over here with Dr. Ballard and then Dr. Baker.

Dr. BALLARD. Just quickly. I think you may be also referring to the article that was just two days ago in the science section of the New York Times about the Lamont declassification of data.

In that case, that was multi-beam data which has a much higher resolution than gravity data. I think it's important to point out, if you had a map of the world in this room, which I strongly recommend, you'll see that the vast majority of the world's oceans is in the southern hemisphere.

There's a certain amount of mining that one can do of the military data base, but their mission has primarily been a mission in the northern hemisphere.

And certainly, one of the things that we need to concern ourselves about, that there are huge stretches of the southern hemisphere that have never had an oceanographic research vessel ever pass over them once, let alone more than once.

And so, again, I think a map of the world would help guide people to know that most of the world's oceans is in the southern hemisphere.

Mr. OLVER. It would be a wonderful exercise in cooperation for you folks, as out of the nine agencies or either of the five, or whichever it is, to figure for us the most descriptive map that could fill that wall of these data.

It would be a wonderful exercise.

Mr. WELDON. Let's move on to Dr. Baker. And just to clarify for our friend and colleague, Admiral Watkins' testimony included statements from the other four agencies that you referred to.

We did not have a long enough table to have the other agencies here, but they are all here on the record and Admiral Watkins alluded to their statements when he made his opening comments.

So those agencies include NASA, the Geological Survey—and who am I missing, Admiral?

Admiral WATKINS. MMS.

Mr. WELDON. Right, MS.

Admiral WATKINS. USGS.

Mr. WELDON. And EPA, right. Thank you.

Now, Dr. Baker.

Dr. BAKER. Let me just comment on the meaning of the word MEDEA, the question.

This grows out of a very strong interest of the Vice President when he was a senator working with the intelligence community, the DOD and the civil community, saying, is there in fact environmental data that is in the classified realm that might in fact be valuable if it were made unclassified?

A group of scientists was formed called the Environmental Task Force, which in fact got the clearances and looked at the possibility of doing this. It turned out to be feasible. And a second group was formed and this second group has the name MEDEA. It's a mythical name which was meant to be somewhat complementary to the name JASON, which is the name for a group of scientists that also advise the DOD on various technical issues.

So MEDEA is the name for a group of scientists who come from, as was mentioned, private industry, the civil sector, the intelligence sector, various agencies, academia. And they are looking in fact at what can be done with the classified data to make it released? What kind of national security concerns have to be there and so on, exactly addressing the question that you asked.

Dr. BALLARD. Just to point out, MEDEA was Jason's wife in Greek mythology.

Mr. OLVER. Do either of you know where the Golden Fleece was? [Laughter.]

Dr. BALLARD. Yes, it was in Georgia, not the U.S., but past Soviet Georgia in the Black Sea.

Mr. OLVER. You're sure of that?

Dr. BALLARD. Pretty much.

[Laughter.]

At least that's where they went.

[Laughter.]

Mr. OLVER. You're sure of that?

[Laughter.]

Mr. WELDON. I thank the gentleman for his questions and thank all of our colleagues for attending this very significant hearing today.

Most of the questions have been answered that I was going to raise. I have a number that I'm going to submit for the record.

I did want to ask one question about a reference made by Dr. Ballard in regard to the competition in America. Five years ago it was the undisputed leader in terms of ocean research. Today, I think you mentioned that you might even question that.

My understanding is that Japan is currently spending significant amounts of money. I think I've heard the figure of a billion dollars being put forward by the Japanese in this area.

Would any of you care to elaborate? And Dr. Ballard, certainly you.

Dr. BALLARD. France, also. I asked Admiral Watkins that yesterday, if we knew those numbers.

It's my understanding that, on a gross national product, France invests more in oceanographic work than any nation.

Do you know if that's true or not?

Mr. WELDON. Dr. Baker?

Dr. BAKER. There's no question that both France and Japan have made national commitments to both oceanographic research and ocean facilities.

And as we look outwards from the U.S., I think Bob is exactly right. These are countries that are devoting a substantial fraction of their research to ocean activities. If we don't do something, they're going to be the leaders.

Mr. WELDON. Is there anyone else who would like to comment on that?

Yes, Mr. Corell.

Mr. CORELL. I'd just say a word or two about the Japanese. Their investments are growing very rapidly. I've met with the leaders of the Japanese ocean research community only two days ago and they reported to me that their budgetary increases over the next several years at JAMSTEC, which is a part of the science and technology agency, are going to grow at 20 to 25 percent per year.

They are proposing to the world community to take major steps in support by building a drill ship for ocean drilling. There are many other capital investments that the Japanese are planning or are already making in the ocean.

One of the leaders there said, you, the United States, have become the world leaders in space. It is our intention to be world leaders in the ocean.

Mr. WELDON. Interesting. And certainly, that's a challenge for us to deal with.

One other question. And Bruce Alberts, in your testimony, Dr. Alberts, you talk about peer review approach to selecting and funding research projects and that being a foundation of our leadership in science and technology.

The answer to this is obvious, but a good portion of our current ocean research budget is earmarked by the Congress by individual members.

I guess the question I would open up for you is should that change? Should earmarking programs be replaced with competitive peer review?

That's a tough question for you to answer.

Dr. ALBERTS. Well, the last day of November, we released an important report called "Allocating Federal Resources for Science and Technology." That was at the request of this Congress.

I urge you to look at that. It's only 40 pages, 13 recommendations. One of the major ones is that if we want the best value for the money, we have to open everything we can up to competition. It's something that nobody denies. It's just hard to get it done.

But the scientific community urges the Congress to keep your eye on whether or not your funds are being competitively bid for. We all know the importance of that in the market and it's also important in science to get the best value for your money.

Mr. WELDON. I think it was important to get that on the record in this time of shrinking budget dollars, that the scientific community believes that we need to have that peer review process in place.

Another question for Admiral Boorda relative to the autonomous underwater search system, AUSS. My understanding is that that was originally developed for the potential retrieval of space capsules.

Is that currently being used for scientific purposes, and could that be used for scientific purposes involving deep ocean research and deep ocean technology?

Admiral BOORDA. We have looked at that for a number of purposes, one of them being what do we do with dredging materials if we put it in a different place than on land?

Mr. WELDON. Yes.

Admiral BOORDA. I'll defer to Paul on some of the other ideas we might have.

Admiral GAFFNEY. We're looking at all autonomous vehicles and ROVs for collecting data at sea, not just AUSS but other techniques developed by Dr. Ballard and his colleagues for doing routine survey overseas.

One of the early questions we had here is how do we maximize our time at sea? And one of those ways is to get new tools that we can use to double or triple the collecting power of overseas deployed ships.

And these kinds of vehicles would be such tools.

Mr. WELDON. So the answer is then, yes, it can be made available and you're working to that end. Is that correct?

Mr. Roemer has an additional question which I'll allow him to ask now. Mr. Roemer?

Mr. ROEMER. Did you want to follow on? Did you have anything you wanted to follow up on?

Mr. WELDON. Staff has asked me, the Navy research submarine, is it still active and an expanded role in terms of involvement with the scientific community?

Admiral BOORDA. Yes. This last summer, it worked in the Mediterranean. The answer is, yes, it's still active and doing a number of jobs.

Mr. WELDON. Great.

Dr. BALLARD. I can add to that. I was the one that was using it. [Laughter.]

It's been made more accessible to the academic community and it's a tremendous asset. It's being able to do much more work because it's not only a great submarine, but it now has a great support ship that can support remotely-operated vehicle systems and we'll be using it during the JASON project in a few months.

Mr. WELDON. Great. Fantastic.

Mr. Roemer?

Mr. ROEMER. Thank you, Mr. Chairman. Before I ask my question, I have one final unanimous consent request, that the Ranking Member of the entire Science Committee, Mr. Brown's statement be entered into the record.

Mr. WELDON. Absolutely, without objection. And that would include other members as well.

Mr. ROEMER. Thank you, Mr. Chairman.

My final question would be, in light of what we've talked about in terms of cooperation, in terms of sharing resources, in terms of coordinating services, one issue as a member of the subcommittee of NASA comes to mind where, on the TOPEX follow-on mission to do a joint satellite on global ocean circulation, NASA decided to go with the French rather than with the Navy.

I guess one of my concerns might be how might we prevent this from happening in the future so that we get this kind of cooperation and sharing of resources and information, whether they become declassified eventually, whether they become information that goes to our business community.

Admiral, if you can share with us any frustrations that you might have with that final decision and ways by which you might recommend to us on this Committee, which has oversight of both NASA and parts of this, where we might discourage that or try to steer our two agencies together to do that in the future.

Admiral BOORDA. I answer that question really with mixed emotions.

In some cases, we want to do, and it makes sense financially and allows us to free up dollars to do other things. We want to collaborate with other nations. That was one we in the Navy would have liked to have done.

But I don't think we want to make it so hard that when it makes sense to do so, we can't.

That means we have to talk a lot more so that you don't write us into an American-our-agencies-only box, where we can't cooperate when it makes sense.

We in the Navy, for example, do a great deal of cooperation in the ocean environment with other nations, and we don't want to stop doing that. So it's a two-edged sword that we're talking about here. The one that you're talking about did not make me happy. There are others that we're doing that do.

I'd be glad to take that for the record and come back and talk about both sides of that issue.

(See Appendix for the information supplied by Admiral Boorda.)

Mr. ROEMER. Okay. I certainly agree with you, Admiral, that we need to cooperate with other nations and enhance our ability to learn and share knowledge with other nations as well, especially in science.

But when it behooves our country to do one together and to see that cooperation benefit our taxpayer and our oversight agencies and our Navy and NASA, please let us know of your frustrations ahead of time so that we can try to be helpful where we can be, when the joint venture really is in our best interests.

Admiral BOORDA. You bet. Thank you.

Mr. ROEMER. Thank you, sir.

Mr. WELDON. Thank you, Mr. Roemer. And let me thank all of our members and our distinguished panel.

I cannot let this hearing close without thanking the staff. From the National Security Committee, Bill Andahazy, who has done yeoman's work in this area, has just been fantastic in putting together not just this hearing, but the other hearings that we have held and will be holding in the future.

From the House Committee on Science, Richard Russell has been fantastic in working with us and letting this issue come to the forefront and with the cooperation of the Science Committee.

And from the Committee on Resources, John Rayfield has been fantastic in making sure that we have a coordinated approach.

It's very difficult to bring three committees as powerful as these three committees, from an authorization standpoint, to come together to agree that we have to work together on this issue if we're going to get the visibility within the Congress.

Today, it was a rather long hearing, four hours. We had 24 members of Congress stop by, which I think in itself is an indication of the importance that members place on this subject. Others would have been here, but had conflicts. There is a major briefing underway on Bosnia, as most of you know, right now.

Our support for this issue is not just with one hearing. Make no mistake about it. This is not going to be a passing thing. I know, Admiral Watkins, that's your concern. You know me better than that. That's not going to be the case.

This is a long-term commitment. This is a coordinated effort. We have raised the awareness through a series of hearings. This is the culmination of the first wave of those hearings. We ask you to fulfill your part of the task ahead of us and to meet the challenge of coordinating those entities involved with oceanographic efforts.

We can't do that. You've got to coordinate that and you're already, I think, along the way.

What our task and challenge is is for us to coordinate within the Congress, the committee structures, working with the Administration, and getting the visibility of the appropriators and the other bodies to make things happen.

I don't think we have to have such a grandiose scheme involving billions of dollars. That's not needed right now. What's needed is a full focus that will allow for better coordination and better awareness.

Those of us who sit on the Science Committee and who support outer space research are not necessarily supporting this in lieu of that support. In fact, we think the two ought to go hand in hand.

But we are making a commitment and I'm making a personal statement that we will follow through after this hearing is concluded and that we will use our voice and our vote to make sure that we provide the proper mechanisms to allow you to better do your job and better serve not just the people of America, the environmental concerns that we all have, the security concerns that we all have, and the concerns of the people throughout the world.

Thank you all. The hearing now stands adjourned.

[Whereupon, at 2:00 p.m., the hearing was adjourned.]

[The following material was received for the record:]

APPENDIX I

OPENING STATEMENT
BY
GEORGE E. BROWN, JR.

Mr. Chairman, I want to commend you for holding this hearing today. The coordination of oceanographic research among the participating agencies has been a major management challenge ever since post war science policy began to take shape over 40 years ago. Indeed, no other field of research links defense and civilian interests as strongly as oceanography and I want to particularly recognize the efforts of the three chairmen today in attempting to recognize this fact.

It is natural that we begin to explore ways in this post cold-war era to leverage research assets and more closely define linkages between the mission agencies that best benefit our science objectives.

One of the clearest examples of this potential was the release last year by the Navy of declassified data on sea surface height, salinity, gravity field, seabed magnetics and a vast "treasure trove" of other physical data on the ocean. This was part of an overall program to transition the Nation's cold war assets to greater civilian and scientific use. Such data from defense satellites, submarines, ships at sea, and underwater arrays will be crucial in understanding global change and addressing a vast number of other scientific problems including weather forecasting, pollution, fishery management, mineral exploration, and many others.

It is clear that we face a substantial institutional problem today. From the brief glimpses we have had so far, we know that this data will add substantially to our fundamental understanding of the ocean. We do not yet know exactly how it will augment other civilian observational programs or whether it can substitute for or replace such other programs. Before we can fully understand how to structure the linkages between the mission agencies, we need more experience.

In short, we need to become more serious over the pace and extent to which we declassify potentially valuable data. We also need to find a way to integrate the use of this data into the traditional peer reviewed scientific process while protecting our legitimate national security interests. I am aware of proposals such as the establishment of an "exploitation center" at the Stennis Space Center. We may need to develop such specialized mechanisms and I hope we can fully explore these concepts today and in future hearings.

In closing, I believe we all recognize that we are entering the information era at a very rapid pace. The ability to integrate data from a variety of sources will be key to making the next major advances in science. In a more fundamental sense, it may be our duty as a Congress to ensure that the taxpayer gets the maximum return on our national investment in the assets we will hear about today.

Again, I want to commend the Chairs of the participating Committees today and I look forward to the testimony.

Solomon P. Ortiz

I want to thank the Chairmen and Ranking Members of all the subcommittees for cooperating on this important subject.

Furthermore, I want to particularly commend Chairman Weldon for his active and ongoing interest in oceanography issues and ocean research. During the last Congress, he and I had the opportunity to serve together as a leadership team as Chairman and Ranking Minority Member of the former Subcommittee on Oceanography, Gulf of Mexico and the Outer Continental Shelf.

We had a number of hearings on the future of oceanographic research, potential dual use technologies and cooperation between government agencies, industry and academia.

I look forward to continuing to advance this issue which I believe is very important to the long term defense, as well as national economic and educational security.

1. The Navy has been planning for some time now to terminate many Integrated Undersea Surveillance Systems (IUSS) because of obsolescence or changes in our national security interests.

Is it possible to hand over systems no longer needed by the Navy to civil agencies for research or for support to industry?

2. What NOAA research is necessary to maintain adequate information to allow fisheries managers to carry out their responsibilities?

What NOAA research is crucial to coastal managers, and those who live in the coastal zone?

Are the current methods of conducting that research and delivering results to users effective?

3. How can NOAA best carry out its undersea research?

As you know, for some time I have been interested in the NOAA National Undersea Research Program.

Although I believe the program has provided an excellent contribution to our ocean studies, I continue to be very concerned about the lack of basic research that takes place in the Gulf of Mexico, a body of water with a very concentrated amount of economic activity for our nation in terms of fisheries and oil and gas activity, not to mention the vital role for national defense.

I believe that a major contributor to the large disparity in funding for undersea research in the Gulf of Mexico in comparison to other areas of the country is lack of comparable undersea research dollars being spent at educational facilities in the region.

How steps can we take to address this disparity and establish a stronger on-site undersea research program immediately adjacent to the Gulf of Mexico?

APPENDIX II

HOUSE NATIONAL SECURITY COMMITTEE
SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT

HOUSE NATURAL RESOURCES COMMITTEE
SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS
&
HOUSE COMMITTEE ON SCIENCE
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
JOINT HEARING ON: DUAL-USE OCEANOGRAPHIC PARTNERSHIPS
25 JANUARY 1996
QUESTION FOR THE RECORD
QUESTION NUMBER 1

REPRESENTATIVE FARR: Admiral Boorda, I noticed on page 8 of your testimony, reference to Fleet Numerical and NOAA's partnership in dual use products that are transferred to the private sector. Did you know that NOAA closed the Ocean Applications Branch? You might want to ask Dr. Baker how we are going to get data into the Fleet Numerical's private sector. I [sic] did a great job and local Navy and NOAA employers feel a big gap has occurred.

ADMIRAL BOORDA: I understand that, driven by budget shortfalls, NOAA closed their Ocean Applications Branch in October 1995. As an interim measure to avoid an interruption in the public distribution of Navy data, NOAA executed a short-term contract with a commercial firm to continue the service. We continue to work closely with NOAA to develop a long-term strategy for public access to real-time Navy-unique data.

HOUSE NATIONAL SECURITY COMMITTEE
SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT

HOUSE NATURAL RESOURCES COMMITTEE
SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS
&
HOUSE COMMITTEE ON SCIENCE
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
JOINT HEARING ON: DUAL-USE OCEANOGRAPHIC PARTNERSHIPS
25 JANUARY 1996
INSERT FOR THE RECORD
PAGE 90 LINE 2108

"The information follows:"

There are a number of DOD telecommunication technologies that could possibly allow scientists to access unclassified oceanographic data from military platforms without having to physically be there.

Navy's emphasis on data collection is, as I have said, to provide real-time data to the warfighter to describe the battlespace environment. In many cases, it would be inappropriate to make the data--and the military platforms location--publicly available in real time. In many cases, our data collection comes from within the Exclusive Economic Zones (EEZ) of other countries. Navy uses cooperative agreements with coastal countries to gain access to data in their territorial seas which would otherwise be inaccessible. Any limits on public release of the data under these agreements must be honored. With our current focus on littoral areas of the world, much of our data collection comes from within the Exclusive Economic Zones (EEZ) of other countries. Because of Law of the Sea issues, mixing military survey data collection and marine scientific research in foreign EEZs can be problematic and would have to be approached very carefully.

Despite all these caveats, there are certainly unclassified/unrestricted Navy collection efforts, especially in open ocean areas, that could be considered for some form of realtime access ashore.

HOUSE NATIONAL SECURITY COMMITTEE
SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT

HOUSE NATURAL RESOURCES COMMITTEE
SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS
&
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SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
JOINT HEARING ON: DUAL-USE OCEANOGRAPHIC PARTNERSHIPS
25 JANUARY 1996
INSERT FOR THE RECORD
PAGE 145 LINE 3484

" The information Follows:"

Navy's military survey ships are operated ~~under~~ the technical control of the Naval Oceanographic Office, Stennis Space Center, Mississippi. The USNS PATHFINDER and SUMNER are now operating, during their first year, in U.S. waters as they complete their test and evaluation phase. The USNS BOWDITCH will be delivered late this summer and will go through a similar year-long test phase in U.S. waters. The ships are available and convenient during these periods for in-port tours and/or at-sea demonstrations of survey equipment and operations. Because the schedules for at-sea times change frequently, it would be best to contact CDR Darrell Smith at 601-688-5103 to arrange a time for a VIP visit.

There are two opportunities for members of Congress to visit a Navy sponsored ice camp. During the Spring, the period 14-20 April 1996, we will be sponsoring a research effort on acoustic propagation in the Arctic Basin. The ice camp will be established in the eastern Arctic, north of Alberta, Canada. The camp can support up to 10 visitors at a time.

We are also scheduling an ice camp for the fall of 1997 along with an unclassified arctic submarine exercise, SCICEX-97. The camp will be staged from an ice-breaker providing an excellent opportunity to view arctic scientific research for a VIP visit. The Navy point of contact for these ice camp visits is LCDR Don Kelso, Navy Office of Legislative Affairs at (703-695-4172, FAX 703-693-0656).

HOUSE NATIONAL SECURITY COMMITTEE
SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT

HOUSE NATURAL RESOURCES COMMITTEE
SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS
&
HOUSE COMMITTEE ON SCIENCE
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
JOINT HEARING ON: DUAL-USE OCEANOGRAPHIC PARTNERSHIPS
25 JANUARY 1996
INSERT FOR THE RECORD
PAGE 160 LINE 3862

" The information Follows:"

MEDEA - Measurement of Earth Data for Environmental Analysis.

HOUSE NATIONAL SECURITY COMMITTEE
SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT

HOUSE NATURAL RESOURCES COMMITTEE
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JOINT HEARING ON: DUAL-USE OCEANOGRAPHIC PARTNERSHIPS
25 JANUARY 1996
INSERT FOR THE RECORD
PAGE 175 LINE 4231

"The information follows:"

Reference: REPORT ON CONVERGING NASA/NAVY ALTIMETRY MISSIONS, MAY 1995:

perations
Dept. of the Navy

This report is a NASA/DOD response to the National Defense Authorization Act (House of Representatives Report 103-701, Section 258) and the FY1995 NASA Authorization Bill passed by the House (HR 4489), which required the Secretary of the Navy and the Administrator of NASA to jointly conduct a study on the convergence of the NASA Earth Observing System (EOS) radar altimetry mission with the Navy GEOSAT Follow-On (GFO) Program.

The DON proposal was to create a Navy/NASA partnership since data coverage and U.S. government costs for the proposed NASA/NAVY GFO-2 were competitive with the U.S./French TOPEX/POSEIDON FOLLOW-ON (TPFO). As outlined in the referenced report, it was decided that continuation of the U.S./French relationship in space collaboration was an overwhelming reason to select TPFO over GFO-2. There was legitimate concern that selecting a U.S. - only option would raise doubts about NASA's intentions with our international partners and compromise NASA's ability to secure other international collaborations in the future, such as the Space Station.

Navy downsizing and decreases in funding have led the Navy, as well, to leverage international partnerships as a means to continue mission objectives. We have cooperated with U.S. agencies that also include international partners, such as RADARSAT (Canada), and the European Space Agency (ESA). The National Polar-Orbiting Operational Environmental Satellite System (NPOESS) will include DOD Services (Air Force, Navy, Army), NOAA, NASA and European agencies (EUMETSAT). Through this partnership, the U.S. provides two polar-orbiting satellites with the Europeans providing the

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25 JANUARY 1996
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PAGE 175 LINE 4231 (Cont.)

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third. From DOD's point of view, we can get a sufficient "refresh" rate for global satellite imagery to support our missions and save U.S. taxpayers the cost of the third satellite.

THE VICE PRESIDENT
WASHINGTON

December 6, 1995

The Honorable Curt Weldon
Chairman
Subcommittee on Military Research
2452 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Chairman:

As you know, the topics on which the Committee will focus during this series of hearings have been of interest to me for some time, and I am pleased to have this opportunity to share my perspective. As President Lyndon Baines Johnson said during his tenure, "The waters which flow between the banks belong to all the people." While the President was speaking about a domestic issue at the time, his message resonates today.

Oceans cover 71 percent of the Earth's surface, and we face a common threat to this precious resource. In this time of lean budgets, creative efforts to exploit existing research and technology efforts for dual purposes are not only sensible but essential. The United States has tremendous resources which only have to be harnessed, and the Committee's hearings represent a significant step in that direction.

As we approach the 21st Century, I welcome efforts to ensure that our country is well prepared to act on the basis of the very best data. I particularly want to thank you for your efforts in this regard. Your ideas and insight on these issues are important to me, and your continued support is essential.

Again, please accept my very best wishes for a productive series of hearings.

Sincerely,

Al

Al Gore

AG/jec

TRENT LOTT
MISSISSIPPI

MAJORITY WHIP

ARMED SERVICES
CHAIRMAN, SUBCOMMITTEE ON STRATEGIC FORCES

COMMERCE, SCIENCE, AND TRANSPORTATION
CHAIRMAN, SUBCOMMITTEE ON SURFACE TRANSPORTATION AND MERCHANT MARINE

BUDGET

United States Senate

SUITE 487, RUSSELL SENATE OFFICE BUILDING
WASHINGTON, DC 20510-2403

245 EAST CAPITOL STREET
SUITE 226
JACKSON, MS 39201

3100 S. PASCAGOULA STREET
PASCAGOULA, MS 39567

#1 GOVERNMENT PLAZA
SUITE 428
GULFPORT, MS 39501

P.O. BOX 1474
OXFORD, MS 38655

200 E. WASHINGTON STREET
SUITE 145
GREENWOOD, MS 38930

April 17, 1996

Representative Curt Weldon
2452 Rayburn HOB
Washington, DC 20515

Dear Curt:

Thank you for your phone call yesterday regarding the National Oceanographic Partnership Act. I look forward to working with you to push this legislation through the Congress.

Because Mississippi is home to a significant element of the naval oceanographic mission, I follow the activities, funding requirements and mission needs of the oceanographic community very closely. I believe that understanding the oceans is fundamental to our national security, as well as to our global economic and environmental well-being. Your National Oceanographic Partnership Act is vital to the success of naval operations and helps focus national attention on ocean policy and programs. I think you are on to something -- your efforts will help ensure our world leadership in oceanography is maintained well into the 21st century.

I am working to include the national security portion of your act in the Senate DOD Authorization bill. While there will be some differences between your stand-alone bill and what I include in the Senate DOD bill, I will help you in conference. You might want to call Bob Smith on this issue as well. He is the SubCommittee Chairman I have been working with on this effort.

I personally think this effort is right on the mark! Thanks again for initiating this bill and I will support it from this side of the Capitol.

Sincerely yours,

Trent

Trent Lott

TL:tew

APPENDIX III

STATEMENT FOR JOINT FIELD BRIEFING

to

Subcommittee on Military Research of Development of the House National Security Committee,
Subcommittee on Energy and Environment of the House Committee on Science, and
Subcommittee on Fisheries, Wildlife and Oceans of the House Committee on Resources

by

DR. MARGARET LEINEN

DEAN, GRADUATE SCHOOL OF OCEANOGRAPHY and
VICE PROVOST FOR MARINE PROGRAMS
UNIVERSITY OF RHODE ISLAND

Mahan Conference Center, Spruance Hall
Naval War College

January 22, 1996

Good morning, My name is Margaret Leinen, and I am the Dean of the Graduate School of Oceanography and Vice Provost for Marine Programs at the University of Rhode Island. I want to thank you for the opportunity to comment on mechanisms to create effective information and technology transfer partnerships to make the most of our national oceanographic resources and assets for defense and non-defense industries. In addition to my academic perspective on this issue, I serve as President of The Oceanography Society, a professional society for oceanographers, and have served at the Chair of the Board of Governors of the Joint Oceanographic Institutions, a consortia of the nation's major oceanographic research and educational institutions.

THE IMPORTANCE OF OCEANOGRAPHIC RESEARCH TO NATION'S ECONOMY AND EDUCATIONAL RESOURCES

Economy

The marine sector of American industry is broad, diverse and large. It includes not only ocean technical industries of the sort typical of defense-related industry, but the products also include food resources (fisheries, aquaculture, seafood safety, technology and marketing), transportation (shipping and ports), recreation (boating, marinas, beaches and other marine attractions), and non-food resources (oil, minerals, sands, gravel and construction material). In addition, each of these sectors of the marine economy is supported by a vigorous technical support industry (fishing technology and seafood processing; nutrients, pumps and other aquaculture technologies; positioning, mapping and charting technology for transportation, as well as goods handling technologies for ports). Finally, environmental technology has become an industry in its own right. Monitoring instrumentation and services (such as water quality monitoring), and management activities (e.g. oil spill cleanup) are important service ocean industries.

The marine industry of the country is a major industry, not a restricted or anecdotal area of work in which a few high tech companies make electronic gizmos or ships for defense. In Rhode Island the combined marine-related businesses and industries account for 10% of the Gross Domestic Product of the State. In some states, like Hawaii and Florida, the percentage is even higher. Furthermore, many of these fields are ones in which we are the acknowledged world leaders in information and research, but not in goods production (such as aquaculture and its technology). Thus, there is much room for economic growth in this sector of the economy..

An important corollary effect on the economy is that because of the enormous attraction of coastal areas for business and for quality of life, the Department of Commerce estimates that 43% of the jobs in the country are in the coastal zone - our ocean interface. This means that the quality of life for a large fraction of our wealth-producers is closely linked to the coast and ocean and to their effective management. These thoughts are close to the hearts of Rhode

Islanders this week with the terrible environmental tragedy of last Friday's grounding of the *North Cape* oil barge.

Educational Resources

As is the case for other major industries in the US like health and agriculture, marine-related industry and business has fostered strong links with our nations' higher educational institutions and the interdependence of the two is the key to our economic well-being as well as our marine military advantage.

The intense love for and scrutiny of our coastal and maritime resources on the part of the American public is reflected in the interest in marine education at every institution that offers it. At the University of Rhode Island, 10% of entering undergraduates wish to major in subjects that will allow them to work in marine-related service, business and industry

WHAT KIND OF PARTNERSHIPS ARE IN PLACE OR SHOULD BE?

What is a partnership?

At the heart of this discussion is our agreement that we need to and will work in a new way in the future - in partnerships. Key elements of partnerships are that partners plan together, they execute work together, and they evaluate the results of their mutual work together. Subcontracts and consulting are not partnerships. We have a long tradition in environmental sciences of such partnerships. Traditionally the most effective partnerships between the academic environmental community and federal agencies have been joint research institutes at Universities or federal agencies (NOAA Joint Institutes) or jointly operated research partnerships such as the agricultural land-grant and SeaGrant models.

University partnerships with state government are common and there are many effective examples. In Rhode Island the Coastal Resources Management Council began with a University of Rhode Island partnership to establish the basis for coastal policy and for policy implementation.

Our partnerships in the marine field have not traditionally included the private sector, but this is critical now. At the University of Rhode Island, we believe that we have pioneered an important new structure in which marine industries can interact with the University. It is called the Ocean Technology Center and will be discussed in more detail by Dr. Jeffrey Callahan, its director. This partnership between the University, the business community, federal mission agencies and the National Science Foundation, provides an effective mechanism for academic research to be planned together with private business. In addition, this structure has provided a framework attractive to additional investment by the Department of Commerce through an Economic Development Administration grant and to investment by the State of Rhode Island in establishing the center as a broader center of excellence in marine economic development.

HOW SCIENCE AND TECHNOLOGY DEVELOPMENT AGENCIES AND PRODUCT USERS, PARTICULARLY INDUSTRY, CAN HELP DEFINE THE NATIONAL RESEARCH AGENDA IN OCEANOGRAPHY

I believe that the nation's oceanographic research and educational institutions have, in collaboration with NSF, mission agencies and the private sector, developed an important new mechanism to define the national research agenda in oceanography and marine-related science. We have developed the Consortium for Oceanographic Research and Education (CORE), of which I know that you are aware. I served as President of the Joint Oceanographic Institutions during the formation of this new group. We have worked with the agencies, private business and with Congress to develop mechanisms by which we can engage in a dialogue about the National research agenda. We believe that this new mechanism substantially enhances those which have been present before.

The National Science Foundation and several of the marine and environmental mission agencies have provided many opportunities for researchers and educators to come together to identify appropriate national research goals in oceanography and programs to reach those goals. The private sector has rarely been a part of those discussions, but needs to be in the future. I believe that the goals of CORE provide opportunities in which this can take place. It is essential that the private businesses and corporations assist us by providing a perspective and where the US marine industry should be in the future. How the industry intends to achieve such goals and how Universities can assist such goals through their research. In other industries such links are close and Universities are very aware of the economic opportunities for the industry -- think of the agricultural industry or the pharmaceutical industry. No such approach has been identified in oceanography and marine-related fields, but is necessary.

Such agenda-setting discussions rarely come as a the result of a single government-sponsored conference or workshop, but through the active participation of the business community in the professional life of the field and through the active involvement of academe and federal agencies in consulting with business. This has not been a hallmark of our field, but must become one. Some professional organizations, like The Oceanography Society, of which I am the president, seek to ensure the broad participation of the business community in our profession. We welcome the opportunity to work with federal agencies and the Department of Defense in making this happen.

THE DEGREE TO WHICH THE DEPARTMENT OF DEFENSE CAN CONTRIBUTE TO OCEANOGRAPHIC RESEARCH CONDUCTED BY NON-DEFENSE AGENCIES AND INSTITUTIONS THROUGH DUAL-USE TECHNOLOGY AND DEVELOPMENT

There are several opportunities for collaboration in which the Department of Defense can contribute to oceanographic research conducted by non-defense agencies and institutions. The first type comprises opportunities for dual-use of technology and facilities that the Department of Defense wishes to maintain in active service. This, of course, would include laboratories like the Naval Undersea Warfare Center, centers like the Naval War College and other active facilities, but also platforms like ships and satellites, and other sorts of facilities.

The second opportunity is presented by facilities and platforms that the Department of Defense feels can no longer be defended for government support. We have seen active discussions of dual-use of some facilities, such as the SOSUS arrays, but need to also discuss the transfer of facilities that the Department of Defense no longer believes are necessary, but could be extraordinarily valuable to the academic community, such as specialized testing facilities and laboratories. Our national investment in such facilities could be enhanced by transferring their operation to academic institutions or to business/academic consortia far more effectively than by shutting them completely.

Finally, I believe that the Department of Defense has not fully described the essential role that it plays in state of the art research in oceanography to the private and the business sector. I have discussed opportunity with the Office of Naval Research for internships, seminars and workshops to facilitate such communication. I believe that we can all take an active role in such discussions. And we at the University of Rhode Island look forward to taking a leadership role in making such interchange possible through programs of the Ocean Technology Center.

UNIVERSITY OF
RHODE ISLAND

STATEMENT FOR JOINT FIELD BRIEFING AT NWC ON JANUARY 22, 1996

Good morning. I am Jeff Callahan. In my remarks I am going to discuss an existing industry/government/academic partnership known as the Ocean Technology Center, of which I am director. The Center is located at the University of Rhode Island- about 10 miles west of here across Narragansett Bay- and is part of the National Science Foundation's Industry/University Cooperative Research Centers Program. As an NSF I/UCRC, OTC represents a highly effective model for fostering collaborative research between industry, government, and academe and for leveraging federal R&D resources.

As you probably know, the National Science Foundation established the I/UCRC Program a little over twenty years ago for the expressed purpose of improving the process by which scientific and technological research results are transferred to American industry. Beginning with one center in the mid-1970's, the Program has now grown to include over 50 centers at universities throughout the country. Each one focuses on a different field of research; OTC is the only one that specializes in ocean-related science and technology.

All of NSF's I/UCRCs operate under similar rules: We recruit members from industry and federal agencies that have an interest in the research performed by our center. The members pay an annual membership fee that averages about $25,000, and in exchange they receive access to all research results, including royalty-free rights to any intellectual property that is generated from the research, and access .to research staff and facilities at URI. Because they fund the research activities of the Center, the members also determine its research agenda, thereby ensuring that it remains relevant to them.

The highly favorable leveraging I spoke of earlier results from the fact that virtually all the research performed by these centers is funded by membership fees and other monies generated by grants and contracts, not by NSF. The total annual NSF budget for the I/UCRC program is about $4M. That $4M results in over $60M annually in membership fees, university contributions, and other funding. That is, every dollar NSF puts into the program generates almost 15 dollars in research support.

OTC is one of the newest I/UCRCs, having begun operations a little over two years ago. We currently have eight members: five ocean technology firms and three federal laboratories whose missions are ocean related. Six of our members- NUWC and all five industry members- are from the southeastern New England region. That most of our members are from this region reflects the fact that there is a cluster of such companies and federal labs here. Our membership is

The University of
Rhode Island is an
affirmative action and
equal opportunity employer

OCEAN TECHNOLOGY CENTER
Narragansett Bay Campus, Narragansett, Rhode Island 02882-1197
Phone. 401-~~792-6709~~ Fax 401-792-6811
874-640

a cross section of the ocean technology industry. Most of the companies in this sector are small, typically employing fewer than 50 people. A few - like Raytheon, an OTC member - are large, and they frequently are (or have been) defense firms. Ocean technology companies as a group are entrepreneurial, creative, and aggressive, and they produce world class products. A large proportion of their sales - often more than half - are from outside the US.

Given the makeup of our center, we have focused our R&D program on two segments of the ocean technology spectrum: ocean acoustics and marine environmental monitoring systems. In the two years of OTC's existence, we have undertaken five "core" projects that are of general interest to all our members, and we have also performed several proprietary projects that have been funded separately by members with specific interests in those projects. Two examples of our core program are a project to develop a miniature winch that sits on the ocean bottom and samples the water column from the bottom to the surface by unreeling a small sensor package; and a system known as COASTMAP for collecting and analyzing marine data from a network of sensors along the coast and then using the data to forecast conditions in the future. We are in the midst of developing a plan for a major expansion of our research program into marine foods technologies-- fishing, aquaculture, and seafood processing- and we are seeking funding for the expanded Center from the state of Rhode Island under its Research Centers of Excellence Program.

While the I/UCRC Program is very effective in terms of leveraging NSF funds, the aggregate statistics mask some problems that are specific to the ocean technology industry. These problems stem from two factors: (1) the small size of many companies in this industry and (2) the critical role that federal R&D funding - specifically DoD and NSF - plays for all of them, even very large firms. I have already pointed out that many of the companies in the ocean technology sector are small, and their small sizes limit the amount they can invest in R&D. One suggestion I would make to help small firms like those in our industry invest more in R&D is establishment of a federal tax credit for investments in cooperative R&D partnerships like the OTC.

Let me now turn to the second factor- the role of federal R&D funding in ocean technology. It is no secret that federal funding is extremely important for ocean R&D in general. The Navy plays an especially important role in supporting applied scientific research and technology development in the ocean. The reason for that support is obvious: the Navy has a need to understand the environment in which it performs its mission. The collapse of the Soviet Union has led some to conclude that the need for investment in antisubmarine warfare - the mission area that drives much of the Navy's oceanographic R&D program - has been greatly reduced. This attitude results in reductions in funding related to ASW, and is having a direct impact on the ocean technology industry.

I believe that this attitude is short sighted. There is no doubt in my mind that the US is today the world leader in essentially all aspects of ocean technology because of the investments made by the Navy and other federal agencies over the past fifty years. The technology that has come out of that investment has been crucial to our efforts to understand the ocean and to improve national security in terms of both defense capability and economic strength. It is, in a very real sense, the infrastructure that enables the country to utilize the ocean for the economic and social benefit of all its citizens. For example, today's underwater search and recovery capabilities, to say nothing of the pinpoint navigation that is required in many commercial ocean operations, are the direct result of DoD R&D programs.

In the past, the Navy and other federal agencies have been the catalysts for much of the ocean technology development that has occured in this country. For the US to maintain its leadership role in ocean technology, they will have to play that role in the future. Therefore, as the federal government determines priorities for R&D funding in the future, I would urge you to keep ocean technology development high on the list. And as we search for new arrangements for funding and performing ocean technology development in the post Cold War world, I would urge you to continue to encourage partnerships - like the NSF I/UCRC Program- that strengthen the mutually beneficial relationships that exist between the Navy and other federal agencies and the ocean technology community.

file: hearing.rwc

PRESENTATION BY DR. PETER H. CRESSY
CHANCELLOR, UNIVERSITY OF MASSACHUSETTS DARTMOUTH
CONGRESSIONAL HEARING
MONDAY, JANUARY 22, 1996, 11:00 A.M.

Mr. Chairman:

Thank you very much for this opportunity to testify before your important committee. Let me speak both as a Chancellor of a research university and as a former admiral in the United States Navy. I fully support the importance of balancing the budget and reducing the national debt as fast as is reasonably possible. I believe, however, that we should do so in a way that we do not lose the entrepreneurial advantage we have gained through 50 years of defense-related ocean and marine science research. We should not lose the opportunity to create jobs. We should not lose the opportunity to protect the ocean environment. The research foundation development in ocean and marine science, created by our national security effort and particularly by the U.S. Navy, is a national treasure. Others will talk today about the need to continue fundamental research in the ocean and coastal environment. I agree with this requirement, and I believe it is entirely appropriate and in the best interest of the United States and its national security to ensure that appropriate funding flows to our universities and research institutes in a manner that supports national security in the traditional manner, but also concems itself with translating the discoveries we make there in support of our national security in terms of our economy and the environment.

I would like to speak today of how, with relatively small dollars, we can take advantage of a great deal of research that has already been accomplished in submarine warfare and anti-submarine warfare, and in literal warfare particularly in the areas of sensors, instrumentation, communication, and modeling. I believe that the Technology Reinvestment Project and particularly the concept of Regional Technology Alliances (RTA) was fundamentally a brilliant concept. I have no doubt that there may have been administrative flaws and that it may have been reasonable to reduce funding in certain areas, but it was an extremely innovative approach to capturing the technological advances that were the direct outcome of national defense research.

Fifteen months ago, the University of Massachusetts Dartmouth teamed with senior scientists from other universities, including Harvard; Woods Hole; and the University of Rhode Island, teamed with key defense industries interested in conversion such as Raytheon; Sippican; and Physical Sciences Inc., teamed with the Navy Undersea Warfare Center, which is located next door to us here in Newport. We developed a natural laboratory concept entitled "MASSRICON" for Massachusetts, Rhode Island, and Connecticut.

The essence of this proposal was designed to take advantage of the complex waters off the coast of Connecticut, Rhode Island, and Massachusetts extended out to the great fishing grounds of Georges Bank, develop new data collection system, develop new instrumentation concepts, and adapt open ocean and coastal computer simulation models of ocean flows in a manner which would create new opportunities for industry and which would provide a whole new approach to managing the environment in a cost-effective, environmentally safe commercially advantageous way. The area from Boston to Rhode Island to Eastern Connecticut has arguably the richest collection of marine science academic institutions in the nation. It is no accident that it is equally rich in high-tech defense and marine industry. As the associated chart shows, it is also an extremely interesting and dynamic marine region which includes:

- the dynamic interaction of coastal and oceanographic currents.
- some of the world's richest fishing areas.
- extensive commercial and recreational usage of the sea lanes.
- important military applications.

We believe that we have developed the foundation of a unique public/private partnership that can support the environment while supporting commercial and military applications. We believe that:

- we can substantially enhance the marine instrumentation industry by developing cost effective sensors.
- we can develop new concepts for integrating complex data from multiple coastal and ocean sites.

- we can improve our understanding of environmental dynamics in a way that will improve the fishing regulatory process; improve fishing methods; reduce damage to the habitat by fishing

- improve our understanding of the impact of dredging; increase the opportunity for safe dredging; increase our understanding of urban effluent on the environment; improve the ability of industry to operate near estuaries and shorelines

- and most importantly develop a scientifically-based set of algorithms and models that will allow port captains and environmental regulatory authorities a systematic way to deal with environmental specifics of their particular port harbor, estuary, or region in a manner which is safe but commercially supportive.

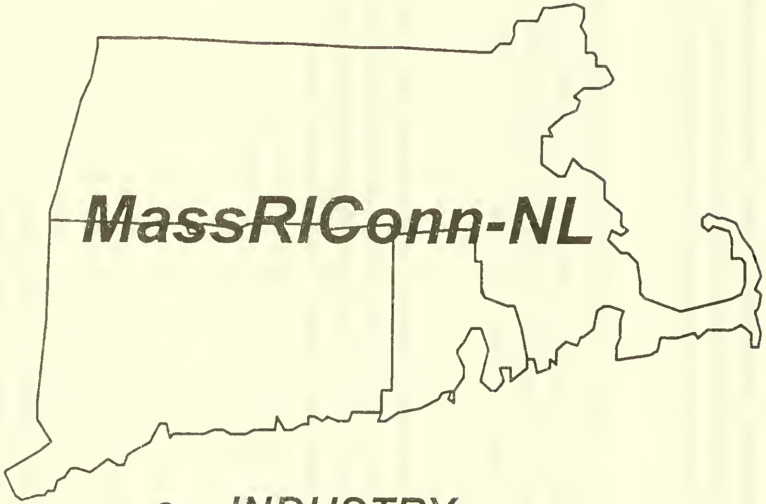
These concepts would be a substantial factor in helping the United States capture a large portion of the world's marine environmental regulatory and remediation industry. This industry is projected to be as large as $250 billion annually by the year 2006. This could mean thousands of well-paying jobs for the United States, a vastly improved regulatory climate, friendly both to the environment and commerce and real progress in fisheries management. This is not, Mr. Chairman, a pie-in-sky idea--we are ready to go with a solid plan.

In April of 1995, Mr. Chairman, this proposal had been ranked Number 1 of 143 by the Technology Reinvestment Project. We had identified $3 million in private funds available to match $3 million in federal funds to launch this important project. A week later, the Regional Technology Alliance money was rescinded by a well-intentioned, budget-balancing Congress. I applaud the Congress' effort to balance the budget, Mr. Chairman. I submit, however, it is now time to review our allocation of research dollars. I submit that programs, such as MASSRICON, deserve your close attention and that the Regional Technology Alliance should be re-established at an appropriate level. Thank you, Mr. Chairman, for the opportunity to testify before your distinguished committee. With your permission, I ask that my statement be included in the record and that a brief outline of the MASSRICON Natural Laboratory Project and its scientific plan be attached to this testimony. I would like to ask permission for my colleagues, Dr. Brian Rothschild, the Director of our Marine Science Center; and Dr. Robert Weiss, a leader in the marine industry, to each make a comment. Thank you, sir!

1/19/96 /ct

MASS-RI-CONN NATURAL LABORATORY

L.I. Sound -Narragansett/Buzzards Bay - Georges Bank



MassRIConn-NL

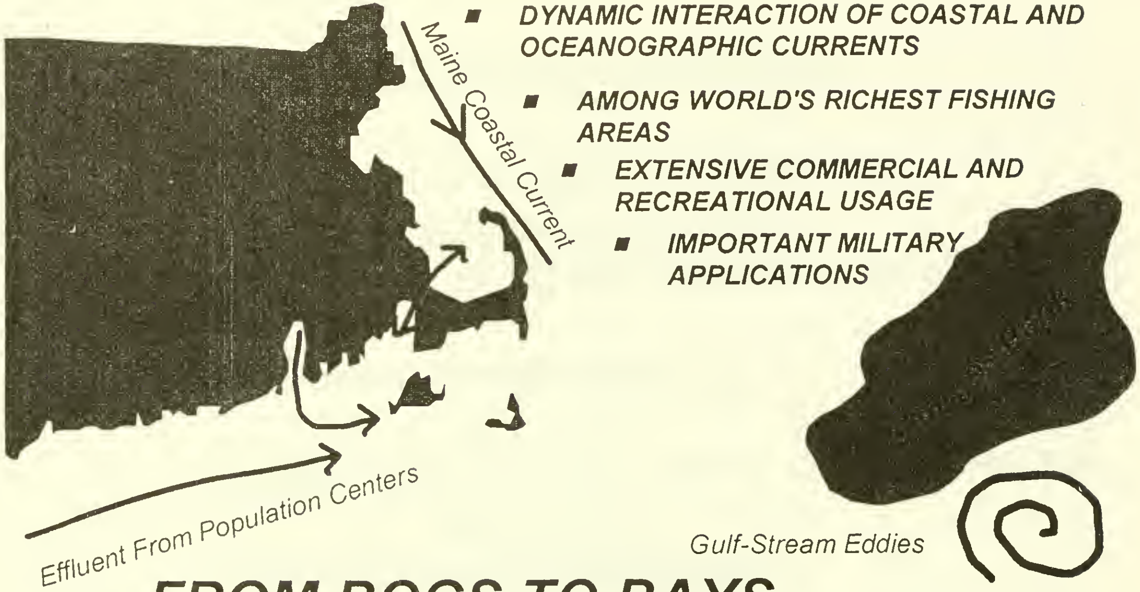
- ***INDUSTRY***
- ***GOVERNMENT***
- ***ACADEMIA***

UMass Dartmouth

PURPOSE

- *OPPORTUNITIES FOR INDUSTRY*
- *MODEL FOR MULTIPLE USE OF COASTAL WATERS*
- *NEW INSTRUMENTATION*
- *NEW DATA COLLECTION/INTEGRATION PROCESSES*
- *SERIOUS COLLABORATIVE RESEARCH*
- *NEW TECHNOLOGY APPLICATIONS*
- *FUNDING*

A UNIQUE MARINE ENVIRONMENT

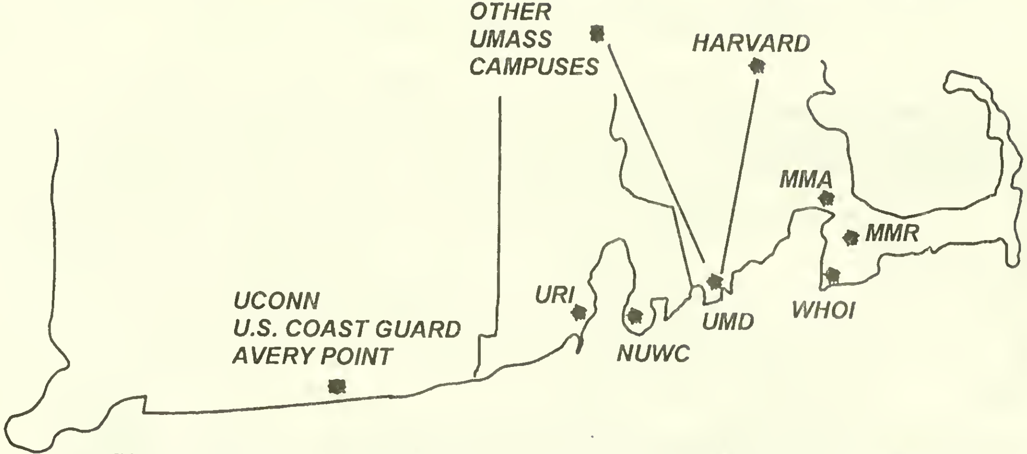


- DYNAMIC INTERACTION OF COASTAL AND OCEANOGRAPHIC CURRENTS
- AMONG WORLD'S RICHEST FISHING AREAS
- EXTENSIVE COMMERCIAL AND RECREATIONAL USAGE
- IMPORTANT MILITARY APPLICATIONS

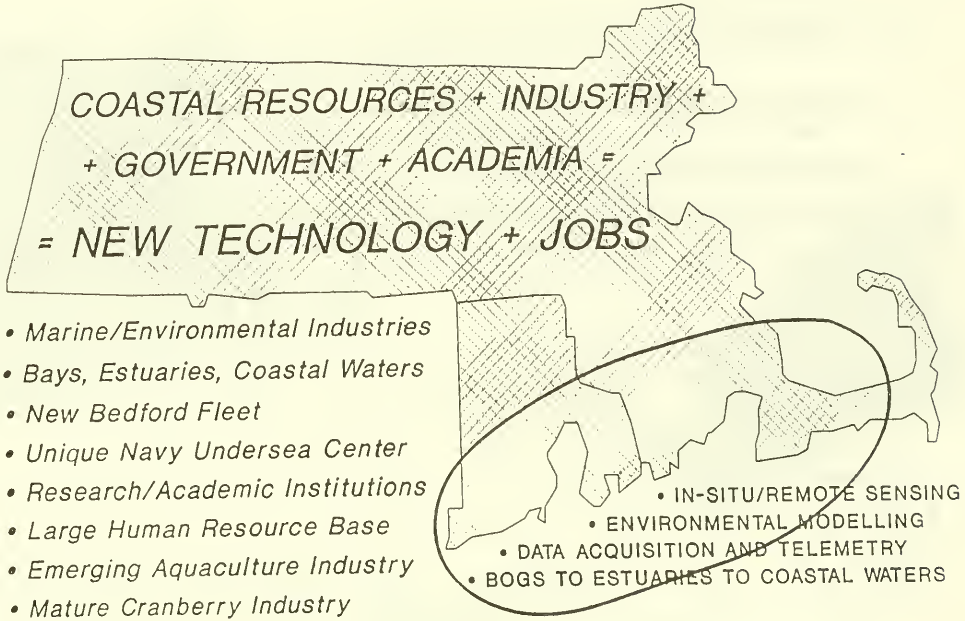
FROM BOGS TO BAYS TO BANKS

UMass Dartmouth

BUILDING ON REGIONAL STRENGTHS



- THE REGION IS POSITIONED TO CAPTURE THE ENVIRO-TECH MARKET
- SUPPORT FROM MASS, R.I., AND CONN STRENGTHENS THIS POSITION
- ASSETS OF THE REGION CAN BE LEVERAGED TO FOCUS ON THE ECO-SYSTEMS FROM L.I. SOUND TO NARRAGANSETT BAY TO BUZZARDS BAY TO GEORGES BANK
- COMMON CORE OF DATA CAN SUPPORT MULTIPLE APPLICATIONS



COASTAL RESOURCES + INDUSTRY +

+ GOVERNMENT + ACADEMIA =

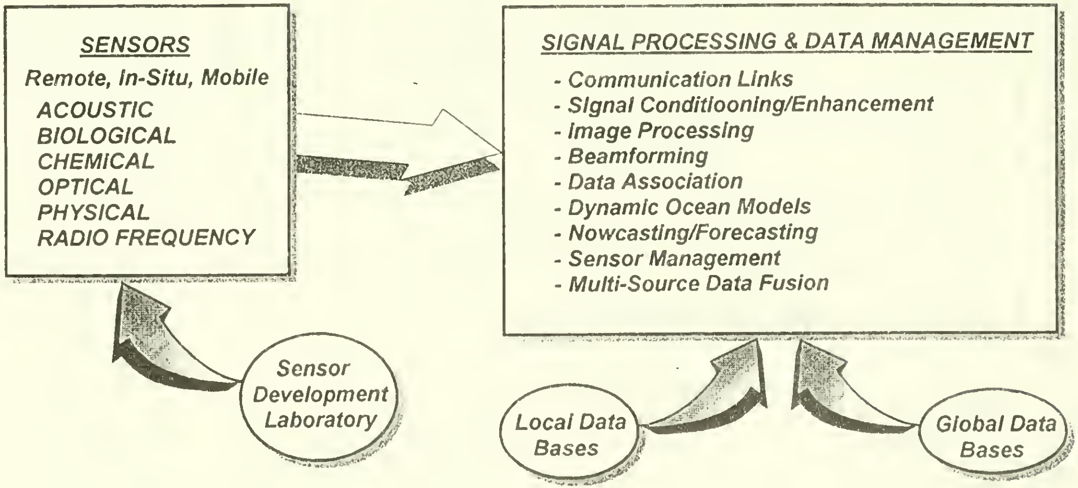
= NEW TECHNOLOGY + JOBS

- *Marine/Environmental Industries*
- *Bays, Estuaries, Coastal Waters*
- *New Bedford Fleet*
- *Unique Navy Undersea Center*
- *Research/Academic Institutions*
- *Large Human Resource Base*
- *Emerging Aquaculture Industry*
- *Mature Cranberry Industry*

- IN-SITU/REMOTE SENSING
- ENVIRONMENTAL MODELLING
- DATA ACQUISITION AND TELEMETRY
- BOGS TO ESTUARIES TO COASTAL WATERS

MassRIConn-NL

A REGIONAL RESOURCE AND NATIONAL ASSET



SENSORS

Remote, In-Situ, Mobile

- ACOUSTIC
- BIOLOGICAL
- CHEMICAL
- OPTICAL
- PHYSICAL
- RADIO FREQUENCY

SIGNAL PROCESSING & DATA MANAGEMENT

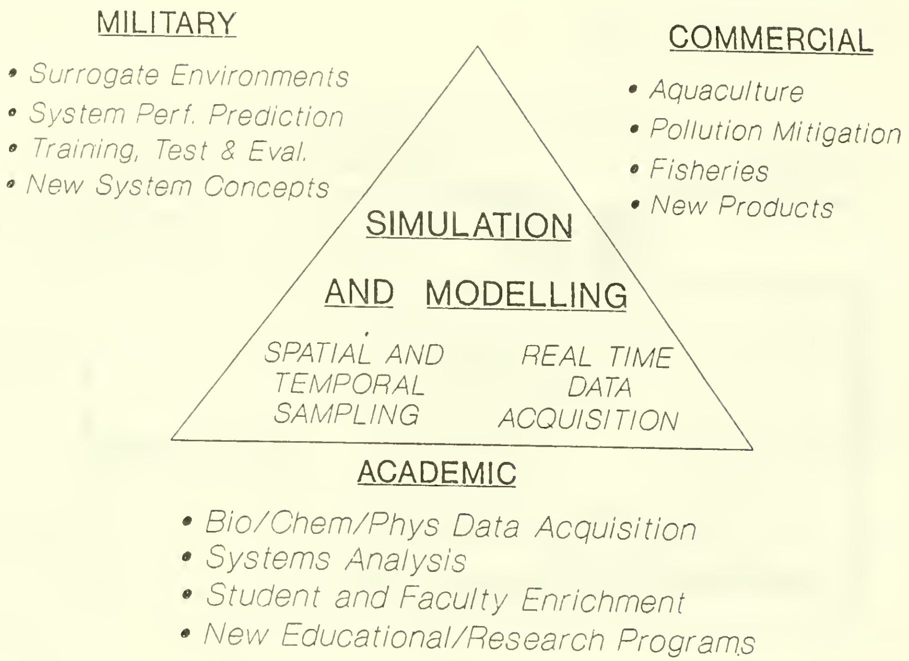
- Communication Links
- Signal Conditiooning/Enhancement
- Image Processing
- Beamforming
- Data Association
- Dynamic Ocean Models
- Nowcasting/Forecasting
- Sensor Management
- Multi-Source Data Fusion

Sensor Development Laboratory

Local Data Bases

Global Data Bases

UMass Dartmouth



MILITARY

- Surrogate Environments
- System Perf. Prediction
- Training, Test & Eval.
- New System Concepts

COMMERCIAL

- Aquaculture
- Pollution Mitigation
- Fisheries
- New Products

SIMULATION

AND MODELLING

SPATIAL AND
TEMPORAL
SAMPLING

REAL TIME
DATA
ACQUISITION

ACADEMIC

- Bio/Chem/Phys Data Acquisition
- Systems Analysis
- Student and Faculty Enrichment
- New Educational/Research Programs

Testimony of Mark D. Gould, Ph.D., Dean of the College of Arts and Sciences, Roger Williams University, Bristol, Rhode Island to the Joint Field Hearing of the House Committee on National Security, Subcommittee on Military Research and Development, the House Committee on Resources, Subcommittee on Fisheries, Wildlife, and Oceans, and the House Committee on Science, Subcommittee on Energy and Environment on 22 January 1996 at the Naval War College, Newport, Rhode Island

Friends,

We are at war. It is not the traditional battleground, but one which is far more serious, for its insidious nature threatens our long-term existence as a country. Any war has winners and losers, and I am quite concerned that we do not lose. Our country is precious and we must fight to maintain it.

Witness what I see now in the southern New England region but not unique to the area:

- fishing banned due to overfishing and pollution
- flight of industry from the inner cities
- economic cutbacks within the defense industry and down-sizing by corporations resulting in loss of jobs
- lowering of educational expectations, especially in the sciences and technology
- societal destruction: increasing crime, violence, drug use, family breakdown
- environmental degradation

The list could continue, and each topic could and should be the discussion for many hearings and debates. However, if we follow the traditional approach to the problems, we will continue to arrive at partial solutions, never coming to grips with the whole. All of the components are inter-connected, but we tend to look at the symptoms of the disease and not at the sources.

Instead, we compartmentalize our systems. For example, fisheries are dealt with by organizations/governmental units such as the Departments of Interior and Commerce, state agencies, local groups, educational communities, consumers, marketers, and of course fishermen. Each of the constituencies has a say and each wants to stake its role in the harvest of the fish. The "common resource," however, can only support a finite fishery, but demand has become infinite, and profits are the bottom-line. Each unit develops "solutions," usually with little or no consultation with the other units. The result is the degradation of the resource (with a corresponding loss of jobs, a decreased food supply, and a deteriorated ecosystem) while no one watches over the whole.

Your hearings must address all the interactions, the whole picture. And what is the whole? It is comprised of people and organisms living and participating within a greater community and the physical world. We must begin to look at all our activities and understand the connections between industry, the environment, and people's lives. The quality of life is a prime concern for all Americans. If your life is shortened by living in a city (as statistics show), if you cannot afford food, and if you do not have a job, your belief in government and country diminishes.
In the long term to maintain a good quality of life and for our economic system to flourish, we have to honor the biological and physical components of the community we live in. In a healthy ecosystem there are many diverse components; we too must be able to integrate our economics, environment, and education to achieve our goals.

As one who has been involved within the educational arena for many years, I am quite concerned that our citizens are increasingly technologically illiterate. Be it the use of computers or mathematics, perhaps a better paradigm would be to study a few topics in depth and generate excitement to learn more. Within the undergraduate marine biology program at Roger Williams University, my colleagues and I provide a broad training to our students. By combining physics, geology, chemistry, and biology, we teach them to see the connections among the disciplines. By using real-life scenarios such as the collapse of the George's Bank fishery, they learn to understand political and economic realities. Such programs demonstrate that oceanography can be an ideal model for understanding and developing broad societal solutions.

So, where do we begin? We have to think of the whole and ask ourselves where should our country be in the future. I would love to give you the perfect solution to solve the forementioned problems. I can't. However, I envision steps and directions which should commence immediately.

I recommend that we begin a collaboration among the components of our national "ecosystem"--economic, educational, cultural, and environmental. Specifically, a national policy can help develop solutions for the future in the following areas:

- education: We need a population that is both technologically and biologically aware. Introduce a coherent and integrated program based on the whole picture to primary and secondary students and teachers, incorporating local field trips, lectures, summer camps, etc. The aquatic environment provides an excellent medium for such study, since the need for water exists in all communities and is important for all life functions. Such a program will result in a better understanding of science and technology, as well as a heightened awareness of the world surrounding us and our connections to it. Children taught by such programs will pass this learning on to their parents.

At the college level, continue to nourish, in lively ways, the interest in science. Marine biology is one discipline which at the undergraduate level provides a thorough understanding of the sciences but does not preclude other fields of employment. Upon graduation we will have a scientifically and technically literate person who can continue in the sciences or other disciplines.

- economics: We need to collaborate with businesses to determine their needs; new economies will develop (example: a crab processor has a waste stream problem, is there a solution for the materials? Yes, the material can be used for medicinal purposes). Technology that was developed for defense can be used for environmental mapping, resource development, etc. Many of tools are available, but what is crucial is the sharing of the materials and beginning to postulate potential uses.

The war we are in is real. Degradation of our economy, our culture, our scientific and technical understanding, and environment make us a poorer country. We must meet the challenge; I applaud you for this hearing today for it is from such collaborative hearings of committees as diverse as these three House Committees that true solutions will come which will address and solve the needs of America.

Thank you.

Role of Woods Hole Oceanographic Institution in Regional and Dual Use Partnerships

Dr. James Luyten
Associate Director of Research
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
January 22, 1996

I have the honor to serve as the Associate Director of Research at the Woods Hole Oceanographic Institution (WHOI). We are the largest private, non-profit oceanographic institution in the country and one of the premier marine science, engineering and education centers in the world.

The Institution's location in the northeast is no accident. It was established here in 1930 on the recommendation by the National Academy of Sciences for the need of an east coast facility with access to coastal and deep oceans as well as to New England colleges and universities.

The Institution is located in Woods Hole, Massachusetts, and is the largest single employer on Cape Cod It is a private institution dedicated to ocean basic research and fundamental engineering, as well as to graduate education. At the present time we employ about 150 Ph.D. level scientists and engineers, including some of the most distinguished investigators in the world. We have an annual budget of $80M. Most research is originated by individual investigators, and funded, through their own individual initiative, by federal agencies such as the National Science Foundation and the Office of Naval Research. Although the Institution has an historical reputation for work in the deep ocean, about 40% of our support and many of our best scientists, are dedicated to the coastal research so important to regional partnerships.

Our Institution has benefited from its geographical setting. Within the village of Woods Hole, there are two important federal laboratories, as well as two other academic institutions. On a broader scale, we benefit from the proximity to several excellent universities in the greater Rhode Island/Massachusetts region. Further, we have historically benefited from the proximity of two major Navy development centers and from the marine technology industry in nearby towns.

We have also aligned ourselves with U.Mass-Dartmouth, Harvard University, NUWC and industry to address problems of the important semi-enclosed bays of this region such as Cape Cod, Buzzards, and Narragansett Bays, as well as the New York Bight and Gulf of Maine. These bays feel tremendous pressures from neighboring human populations, both for recreation and for income. (In fact, we are experiencing a vivid example of this pressure with a major oil spill that has just occurred in the southern reaches of Narragansett Bay.) These are problems that are regional in nature and require regional study and solutions. Lessons learned in one regime are transportable to the others. We bring to the table very high quality science with years of experience, collecting and interpreting data from such environments.

Although emphasis at our Institution is placed on fundamental understanding and development, we are very proud of our historical record of addressing our nation's practical needs. Early work involved studying the New England fisheries and that work continues to today with renewed urgency in the face of the crisis in fisheries in the region. I will say more shortly about fisheries

First, I would like to say some words about Woods Hole's historical partnership with the U.S Navy. This is a story of which we are very proud During World War II, the Institution became a major player in aiding the Navy's research and development.

- We worked closely with the Navy to develop sensors that could be used in submarine warfare as tactical aids for avoiding or breaking detection while optimizing our own sensor/sonar performance. Further, we helped the anti-submarine warfare developers explain the confounding "afternoon effect" that severely limited surface ship sonars.

- World War II research also included seminal research in long-range acoustic propagation, marine fouling studies—essential to ship maintenance as well as to mine warfare; and our work in underwater explosives. We "wrote the book" on underwater explosives' effects that is still a primary reference today.

- These contributions to the nation's defense efforts continued through to the Cold War and up to today We contributed heavily to the early stages of the Navy ocean surveillance system (SOSUS) and to the concept of submarine launched ballistic missiles Our researchers anticipated by 3 decades the need for and feasibility of long range low frequency active surveillance systems. The fundamental knowledge of the oceans and ocean technology contributed in a major way to the successful ASW efforts in the face of the huge submarine threat mounted by the Soviet Union and Warsaw Pact during the Cold War

- Woods Hole has played a key role in the development of oceanographic research platforms and instruments The deep diving submarine *Alvin* is a prime example. *Alvin* was the first successful attempt to give us routine access to the abyss. Continually updated over the years, *Alvin* continues to be the most effective and efficient manned submersible today We are proud to operate this facility for the nation's scientists. *Alvin* also is an emergency salvage asset for the Navy and has on a couple occasions performed that mission very successfully.

WHOI has played a leading role in the development of other technology both for the Navy and the research community at large. I cannot emphasize too strongly how important this technology development has been and will continue to be to the continuing advancement of our state of knowledge of the world's oceans.

Just to mention a few of those instruments. We have developed a family of fiber optic cable based deep ocean instruments ranging from very simple towed instrument sleds to very sophisticated, maneuverable remotely operated vehicles (ROVs) This technology has been transferred directly back to the Navy who are using it for naval surveys. Other instrumentation includes important sensors like current meters, highly sensitive conductivity, temperature and density (CTD) instruments, sediment traps, and deep and shallow water mooring techniques We are deeply involved on the cutting edge of AUV (Autonomous Undersea Vehicle) development

As I have noted earlier, the Institution has a long and distinguished record of working with the Navy on Navy-related problems. We have a long record in other types of ocean research Let me give just one example of immediate relevance

- Our scientists carried out a long-term program of research on the fate and effects of the 1969 FLORIDA oil barge spill that affected the shores of Cape cod. This effort provided guidance for coastal zone managers worldwide and is the underpinning of a significant portion of what is known about the fate and effects of home heating oil spills

In short, Woods Hole basic and applied research has played a proud role in meeting national needs since the Institution's founding in 1930.

The objective of today's hearing is to discuss partnerships, on a regional basis, among business, government and industry.

Our Institution has established several partnerships that meet this description. I would like to provide a few examples.

- We have a formal agreement with the United States Geological Survey (USGS) office in Woods Hole. USGS and Woods Hole scientists interact daily as colleagues and have entered several joint ventures over the years. A good example is the ongoing to work to study the circulation in Massachusetts Bay that is motivated by the need to understand the dispersal of contaminants from the new Boston offshore sewer outfall. this is a complex and emotional issue where rigorous scientific input has been crucial

- We have a formal agreement with the NOAA National Marine Fisheries Service laboratory at Woods Hole. This agreement has helped to foster joint research exemplified by the ongoing GLOBEC (Global Ocean Ecosystems Dynamics) program on Georges Bank.

As many of you know, Georges Bank is an extremely valuable and endangered fishery. In a normal year, the U.S catch from this region is valued at about $800M, most of it flowing into coastal communities in southern New England. Further, the total economic impact of this fishery is enhanced by a multiplier of about 4-8 The loss of this fishery is therefore devastating in the coastal communities that are the home to New England's fishing industry. This fishery has been in a severe decline over the last five years, and parts of it have been closed Intelligent management decisions about how to manage fisheries on the Bank require knowledge of what went wrong and how the physical-biological system operates.

This is where GLOBEC research enters the picture. Woods Hole scientists are teaming up with government researchers, as well as scientists from other academic institutions, to gain a basic understanding of how flow patterns over the Bank act to support the high biological productivity and productive fishery normally found in this region This is a major, ongoing program, but it is already producing important insights that will be of use to fisheries managers

- Individual Woods Hole scientists are carrying out important fundamental research on the toxic chemicals in the marine environment. This includes work on where the chemicals come from how they are removed from the system and what damage they might do Some of this work has concentrated in the new Bedford harbor, providing a definite local benefit

- Wood Hole Oceanographic Institution is a host institution for the Massachusetts Sea Grant program This ongoing program, involving funds jointly from the federal government, the state and local institutions, has specialized in research focused on practical benefits for the local environment and economy. A good example of Sea Grant Research at Woods Hole is that by Drs. Stegeman and Moore on flounder tumors: a problem that is both good science and of practical importance

- Woods Hole scientists are among the world leaders in research on "red tides", the blooms of microscopic toxic marine plants that lead to human health hazards and closing of valuable shellfish fisheries Naturally enough, much of this work has taken place along the coasts of the New England region, and has led to a far better understanding of how toxic blooms are caused and spread.

- Woods Hole ocean engineers have developed close ties with nearby Navy laboratories, such as the Naval Undersea Warfare Center (NUWC) here in Newport This work involved undersea autonomous vehicles that can be used for mine countermeasures, a critical area in the newly-defined missions of the United States Navy In addition, our engineers are providing important contributions to local Navy laboratories in problems involving undersea communications and acoustics

- Most of the above examples have involved cooperations with governmental entities, and the local economic benefits have been relatively indirect. The Institution, however, has very direct partnerships with local businesses, mainly through spawning local small, high technology companies that specialize in ocean instrumentation or in environmental consulting services.

Throughout the previous examples, I have emphasized the partnerships that have a distinctly regional focus. I would like to point out, however, that some of our partnerships having a national focus can still have distinct local benefits. Let me give an example:

- The United States Navy is presently very concerned about problems involving mine countermeasures (MCM) in the coastal ocean. One of the primary issues here is how ocean sediment (sand) scours out or buries mines Thus, the Navy is actively interested in sediment transport in the coastal ocean, and Woods Hole scientists are actively involved in basic research on this topic. Through the Navy's policy of encouraging dual use research, the same scientific and engineering results that will help improve warfighting capabilities will be useful to civilian coastal engineers for dealing with beach erosion and coastal hazards. Beach erosion alone costs this nation hundreds of millions of dollars each year in property damage and attempts at remediation.

I could give numerous, similar examples of Woods Hole partnerships with the Navy that involve advances in coastal meteorology, instrument development and marine pollution.

We are very proud of Woods Hole's track record of partnerships. These efforts have provided, and continue to provide, practical information for a variety of users, and have made good use of increasingly scarce assets We value our regional, as well as national, partnerships, and we hope to make them grow in the future. We applaud the recent governmental trend to break down institutional barriers and allow more effective cooperation among the private, governmental and academic sectors.

We at Woods Hole are, of course, concerned about possible decline in funding for scientific and engineering research and education. The issue is not simply one of the health of our own institution and dependent aspects of the nearby economy. The broader problem is that declining funds could potentially postpone or cancel societal benefits that we see on the horizon. For example, the GLOBEC Georges Bank study promises to revise our thinking about, and management of, this important fishery. A serious decline of funding for this work could allow the continuation of the previous policies that have allowed the present collapse of the fishery Similar concerns could be expressed with regard to all the other partnership examples that I have given.

We encourage our individual scientists and engineers to develop research partnerships outside the academic sector. In the process of doing this kind of research, we strive to ensure that peer review be a central paradigm for awarding money. There are a few specific things that could be done that from the governmental end to encourage further growth of these partnerships:

- Foster communications between academic scientists and the government and private sectors. Our scientists cannot know where cooperation is possible unless they are aware of the key problems in the other sectors. When they find good matches for their skills, they will very likely contribute to solving problems. In addition, it is important that all sectors understand each other's procedures and long-term motivations. Perhaps local symposia of personnel exchanges will be effective for this purpose.

- Encourage managers at governmental facilities and in business to seek partnerships in the private or academic sector. In the long run, this policy could prevent the establishment of duplicative capabilities, and allow more efficient solutions. These partnerships could involve personnel, facilities or both.

- Getting specific jobs accomplished often requires passing money from the business or governmental sectors to the academic sector. In some cases, such as with the Office of Naval Research, the financial arrangements work very smoothly. ONR has an outstanding track record (as does NSF) for ensuring the quality and timeliness of research activities and I would encourage adoption of similar straightforward procedures on a broader scale. Any changes, of course, should not be made without due accountability and protection for those providing funds.

I believe that there is a good deal of potential for expanding regional partnerships among business, government and the academic community. In today's fiscal climate, there appears to be a good deal of motivation on all sides for expanding these ties. With better communications and lowered institutional barriers, I expect to see a substantial growth of partnerships on a regional basis.

East Coast Fisheries Federation, Inc.

Joint Committe Hearing

Committees on National Security; Resources; and Energy and Environment

January 22, 1996 Naval War College Newport RI

Thank you, Mr Chairman My name is James O'Malley I work for the East Coast Fisheries Federation The federation is a trade association of commercial vessels and their crews, processors and wholesalers, support services, and local fishermen's organizations and cooperatives in Rhode Island, Connecticut, New York and New Jersey Member vessels fish from Georges Bank and the Gulf of Maine through the Mid-Atlantic to Cape Hatteras. We fish for traditional groundfish such as cod and whiting and flounder, but also for export species like butterfish, squid, tuna, mackerel and herring, as well as many others.

The greatest opportunities we will have in fisheries will require new sources of data and information for fishermen, for scientists, and for fishery managers. And that is the key message I would like you to take away with you today. Our greatest need is more information about what is going on in the ocean, and we would get that if we had access to the kind of technology we all believe exists within the Department of Defense.

For example, the use of satellite data could be extremely useful in the management, conservation and protection of several species that are of considerable commercial value to all of us, such as large pelagics like tuna and shark, and smaller ones like mackerel and herring. Aerial surveys of bluefin tuna, for example, are limited in time and space, and you miss fish or perhaps double-count them

Satellite data could also be used to assess the oceanographic conditions we associate with concentrations of fish, such as algae blooms, temperature gradients, and gyres. We know, for example, that the success of a spawning year for some species depends on the right conditions of tide and wind to carry eggs to a friendly bottom structure. Perhaps satellites could tell us, much sooner than our present capabilities, of the likely conditions of next year's fish stocks.

P.O. Box 649 • Narragansett, RI 02882
Phone: (401) 782-3440 • Fax: (401) 782-4840

Satellite data could also be critical in the protection of oceanic resources that are of aesthetic, rather than commercial, value The Northern Right Whale is nearing extinction, and timely information about the movements of individual animals may save it as one of this world's great beasts. Populations and movements of other mammals, such as seals and porpoises, are matters of considerable dispute, and perhaps there are ways to resolve those disputes.

Hydroacoustic technology may also be useful in marine mammal issues. There is a nettlesome problem in predation of salmon aquaculture pens by seals. This situation is making life difficult for the salmon farmers in Maine, and poses a barrier to the growth of aquaculture throughout New England. If we could find non-lethal ways to keep those animals away from salmon cages, everybody would be happy, farmers and environmentalists alike. There is also a famous problem in the Ballard locks in Seattle, where sea lions--one animal in particular--are a real threat to endangered wild salmon And in the future, as the ever-growing populations of marine mammals are encountered more frequently by fishermen during their operations, we may need ways to keep them away from our nets.

I do believe that the greatest potential lies in the application of hydroacoustic technology, both to fishery stock assessment and to our ongoing efforts to reduce the catch of unwanted fish, especially juveniles. My expertise, of course, is limited to reading Arthur Clarke's *The Deep Range* about thirty years ago, so I don't want to get in over my head. But the Navy's ability to identify the source of sounds in the water is legend

If we had a system of sensors, for example, that let us know when fish were schooling up to spawn, we could act in time to protect them. We do our best now, and I don't mean to disparage our present state of fishery science. But a report that a mass of spawning fish was a month early, or a few miles away from where they were last year, would be invaluable. This kind of information would be especially useful for the squid resource, a mainstay of this area's fisheries. Squid only live one year, and the stock size is almost completely unpredictable, so the danger of overfishing is greater than with other species. Timely information is critical.

I even envision a time when a sensor on a fisherman's net would tell him, by an acoustic fingerprint, that the fish underneath his boat is too small to catch. That alone would be the greatest technical advance in conservation--and economic return--that could possibly be developed. Coupled with the kind of gear selectivity and conservation engineering work that is now being done, we may come to a day when you only took out of the ocean what should be taken out of the ocean.

I have also been told that there are potentials for the use of magnetics in the field of fishery science, particularly in fish tagging studies which are used to determine migratory patterns of fish. I am getting even further in over my head, but according to one bluefin tuna specialist, they tag fish with devices which depend on recording daylight. That provides information about latitude, but not longitude, and a device which recorded the pattern of changing magnetics on the ocean's floor would fill that gap. Please don't ask me any technical questions about that, Mr. Chairman. I am including written comments from Sebastian Belle, a bluefin tuna specialist with the New England Aquarium, with my testimony.

Certainly, there may be improvements in fishing technology, vessel safety, or enforcement that can be developed with the assistance of the Department of Defense. But I do believe that information about oceanic conditions and fish stocks and fish patterns is far and away the most critical need and the most valuable contribution that can be made in this effort. The Navy has spent generations on the task of identifying "things in the ocean." And if that ability can be turned toward fisheries science and management, spectacular gains could be made. Hardware, technology and equipment can be useful, but sheer information is the greatest need.

This is even more true for the deep water. The National Marine Fisheries Service has always concentrated its research in waters less than 120 fathoms, about 700 feet, because that's where the commercial fisheries took place. But now we are fishing at depths of 500 fathoms and going deeper, perhaps to 1000 fathoms before the year is out We know almost nothing about the great depths and their fishery potentials and vulnerabilities. If we are to safely and profitably use those resources, we need to get as much information about them as fast as we can.

The partnership between the Department of Defense and fishery managers is not as strange as one might first think. One of the chief reasons that countries all over the world declared exclusive economic zones was the realization that fish is a strategic resource. The United States has, within its maritime borders, about 20% of the world's fishery resources; and since fish is about a quarter of the world's animal protein, that resource is of enormous political as well as economic importance. It needs to be defended, which is the job of the Defense Department. Defended, incidentally, both from specific threats and from our own ignorance and sometimes even our good intentions. If this partnership can produce intelligence about the fisheries, count on us, the troops, to use it well.

Thank you

NEWPORT COUNTY CHAMBER *of* COMMERCE

To advance the civic and economic vitality of Newport County

TESTIMONY ON REGIONAL OPPORTUNITIES IN LEVERAGING OCEANOGRAPHIC RESEARCH FOR DEFENSE AND NON-DEFENSE INDUSTRIES AND ACTIVITIES, JANUARY 22, 1996

My name is Keith W. Stokes and I am the Executive Director of the Newport County Chamber of Commerce located in Newport, Rhode Island. Please accept my testimony on behalf of the Board of Directors and the nearly 1000 members of the Chamber. First let me begin by welcoming you to Newport. I can think of no better place to have a hearing on the economic opportunities of employing ocean technology than here in the "Ocean State."

The Newport County Chamber has embarked upon a major regional economic development effort that has provided the catalyst to attract new business investments, assist those existing businesses to grow and prosper, enhance the local tax base, and maximize the competitive business advantages of living within a state that boasts over 300 miles of coastline. This last point is of particular consequence to my testimony before this joint field hearing.

The economy of Newport County and much of southern New England is largely based upon marine-related tourism, defense and defense-related technology industries. Blessed with deep

45 Valley Road • Newport, RI 02842-6377

Tel 401•847•1608 Fax 401•849•5848

harbors and close to major ocean trade routes, Newport in particular is home to a highly diverse group of marine-related manufacturers and service industries. The birthplace of the United States Navy, and the site of today's hearing at the Naval War College, Newport has continued to expand it's national prominence in defense through research and development of sophisticated communications and electronics systems. The Naval Undersea Warfare Center (NUWC), with over 2000 employees, is the principle Navy research, development, test, and evaluation center for submarine systems and sonar research. Private defense-related companies such as Raytheon, General Dynamics, Analysis & Technology, and Aquidneck Management Associates are but a few of the systems engineering firms within Newport County that contract with NUWC.

Newport County is also home to a multitude of oceanographic and environmental engineering companies, including Marine Safety, KVH Industries, and Science Application International. Newport County also boasts direct access to one of the finest oceanography institutions in the world at the University of Rhode Island's School of Oceanography. The school's Ocean Technology Center in particular has been of immense importance to those private sector businesses that have embarked upon opportunities in marine-related applied research. It is noteworthy that the Naval Undersea Warfare Center is an active participant in the Ocean Technology Center's many activities. This has set the stage for an important partnership between defense, non-defense and educational institutions in a collaborative exploration in both dual-use and marine technology development. Without fault to these participants, what is lacking in this strategic partnership is two vital components. First, declining federal funding in oceanography and particularly defense conversion programs has limited the opportunities for these innovative partnerships to progress into the most critical phase of technology development, that is, manufacturing extension and commercialization. We are finding ourselves rapidly becoming a region, and possibly a nation, of having great ideas, but little opportunity for translating those ideas into practical and profitable goods and services.

Second, we must recognize that the private sector is best equipped to create economic opportunity and development. Government will and should continue to play the important role of "pump priming" through support of research and development resources such as the Ocean Technology Center. The private companies that I have identified today are well suited to transfer defense technologies into licensable commercial technologies. It is critical that their access to laboratories and research facilities in institutions of higher education and federal laboratories be fully available.

In closing, there is a unique potential that exists, particularly here in southern New England, to address the emerging challenges of integrating defense technology with ocean technology. This potential will only be realized when government funding is matched with private sector entrepreneurialism and with a dash of higher educational resources. A new mandate leveraging federal resources and assets that is focused upon the singular effort of creating new industries and markets within the ocean and environmental services is greatly needed. A well-conceived package of research and development grants, low-cost financing, and market development assistance will provide the necessary catalyst to expand the nation's economy and its' educational resources. I fully believe this joint committee has the rare opportunity to become the leader for developing new industries and employment opportunities as we head into the new millennium. During the history of our country we have evolved from an agricultural economy, through the industrial revolution to today's technological industrial base. It is only natural that tomorrow's technology driven industries include the natural environment that covers two thirds of our earth.

I would like to thank this subcommittee for granting me the opportunity to speak on this most important issue.

Statement of
J. Craig Swanson
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, Rhode Island 02882
Tel: 401-789-6224
Fax: 401-789-1932
E-mail: cswanson@appsci.com

My name is Craig Swanson and I am a principal in Applied Science Associates, Inc. (ASA). ASA is a multi-disciplinary environmental consulting firm focusing on solutions to marine and freshwater problems. We develop and use computerized tools to investigate complex environmental issues. These models predict currents and tides, transport of pollutants in the water, animal population changes and behavior, and the effects of pollution on aquatic plants and animals.

We presently have a staff of 17 employees. Most technical staff members hold advanced degrees in ocean engineering, biological oceanography, civil engineering, coastal geology, marine affairs or computer science.

Our clients are local, state and federal agencies plus a large range of commercial organizations from small marina owners to large oil companies. Ten years ago 75% of our income derived from state or federal contracts, 25% from the private sector. Today less than 20% of our income comes from the public side, more than 50% from private clients, and approximately 25% is now from foreign clients.

Specific to the ongoing North Cape barge spill at Matunuck, Rhode Island, ASA staff, under a quick response contract with the NOAA Damage Assessment Center, mobilized early Saturday morning to track the ecological impacts of the spill. This effort entailed visiting those locations along the beaches and ponds of southern Rhode Island to make observations of any immediate impact to plants and animals. This effort is continuing. The information collected will be used with a series of computers models developed by ASA to predict short and long term effects to the ecosystem and estimate economic damages to the environment.

ASA has also made predictions of where the spilled oil will move based on our computerized oil spill trajectory models. We have provided this information to various news media during the past few days.

This is a highly visible example of the type of work that ASA performs. Other examples include the analysis of water quality from dredging and disposal operations in Boston Harbor, the impacts of possible spills of a new fuel used in power plants to generate electricity in Tampa Bay and in the United Kingdom, and the study of currents along the coast of Oman for beach erosion and oil spill planning purposes.

We view ourselves as a high technology firm specializing in a niche market. To be successful we have found that we continually need to stay at the leading edge of science and technology in this field. The direction of oceanographic research at the federal level, particularly coastal oceanography, is thus of critical interest to us.

Our experience with federal oceanographic research extends to the first years of our firm, in the early 1980s, when we worked with the Ocean Engineering Department of the University of Rhode Island for the Minerals Management Service of the Department of Interior to develop a computer model system to predict the transport and fate of oil in the marine environment. This early effort helped to form part of the core of the software products and services we provide today.

ASA prides itself in providing software and services that are specifically focused on client needs. With the explosion of personal computer use in the last 15 years this has meant the development of easy-to-understand and use yet powerful software that runs on a PC and not workstation, mainframe or supercomputer hardware. We have found that until recently the federal government research programs were oriented toward more powerful platforms. Even data archived by various agencies were provided in electronic media not well suited to the PC user environment. With the arrival of the Internet, however, this situation is changing. Easier and more extensive access is being provided to the valuable data held by NOAA, EPA and USGS.

A lack of communication from the federal agencies to industry about ongoing and future technologies still exists, however. For instance a news article in *Science* magazine last fall reported about a database of all federal research projects. We have been unable to track down additional information about this database, even enlisting the assistance of the NASA Technology Transfer Center, which has been helpful in other interactions.

On the more positive side, ASA is planning to start shortly a joint project with Brown University, the state of Rhode Island and NASA in the commercialization of remote sensing data for coastal management. This effort, entitled *Narragansett Bay from Space: A Perspective for the 21st Century*, is a partnership using new sensor technologies from NASA, the expertise of Brown University in remote sensing data processing and the end user oriented software capabilities of ASA to provide a pilot system for the state, both for coastal zone management and education. This technology transfer project has the potential for application to other sites in the United States and will be important to emerging nations struggling to manage economic development yet preserve their coastal environments.

Another example of successful academic/industry partnering is the Ocean Technology Center (OTC) at the University of Rhode Island (URI). This NSF-sponsored center brings researchers, federal agencies and the private sector together to develop new marine-related technologies and systems for eventual commercialization. ASA has recently licensed COASTMAP, an environmental monitoring and modeling software system, from the OTC and sees strong commercial potential. In fact we will be installing our first system in Florida shortly.

We are also working with URI to expand the OTC concept with the potential of direct state involvement. The state has proposed funding a series of major research centers of excellence whose purpose will be to stimulate economic growth by technology transfer from the university to private industry. The focus of this expanded OTC will include ocean acoustics, marine environmental monitoring and marine foods technology. The key to success of this approach is a close working relationship among the partners. Private industry must be clear in their assessment of market potential for the technology development that comes from the university. Integrated teamwork is critical for this concept to be successful in creating new jobs.

This approach to partnering can also extend to the federal government and its oceanographic research arms. To the extent possible, research projects must be better communicated to the business community that could commercialize the results. A feedback mechanism, in which small business can help define and focus the proposed outcome of the project, is desirable.

We as a small Rhode Island business have seen few opportunities to partner with federal agencies and believe that the root cause is the lack of incentive for these agencies to interact with the private sector. At the agency level a communications structure needs to be adopted to help information transfer via databases, newsletters, workshops, etc. Incentives to individual program managers and principal investigators in the federal government and academia to identify and promote the results of research under their direction is needed.

One measure of the success of research in oceanography conducted at the national level is how it can affect the well being of its citizens. Clearly the knowledge gained from research that translates into a strong national defense is important. The implicit protection of our environment by devoting resources to a better understanding of the physical and biological processes in marine waters is laudable. The transfer of information, techniques and technology to the private sector is also very important in that the economic viability of marine related industries can be enhanced. As we move to a more service-oriented economy, it is important that the United States remain as a world leader in the effective use of its research to provide employment opportunities for its citizens in the use and export of knowledge.

JOINT FIELD BRIEFING

Regional Opportunities in Leveraging Oceanographic Research for Defense and Non-defense Industries and Activities

22 January 1996

Prepared Statement of Dr. John E. Sirmalis
Technical Director, Naval Undersea Warfare Center

The Naval Undersea Warfare Center (NUWC) is the Navy's full-spectrum research, development, test, evaluation, engineering, and Fleet support center for submarines, autonomous underwater systems, undersea offensive and defensive weapon systems, and countermeasures associated with undersea warfare.

NUWC, headquartered at Newport, Rhode Island, has two major divisions, one at Newport and another at Keyport, Washington. In addition, NUWC detachments exist across the continental United States, as well as Hawaii and the Bahamas.

Areas of technical excellence at the Newport Division include **ocean physics**, **hydrodynamics**, **acoustics**, signal processing, **undersea range and materials technologies**, numerical modeling and analysis, engineering analysis, information processing, **warfare simulation**, **submarine electromagnetics**, **unmanned undersea vehicle propulsion and control**, and weapon systems targeting and control.

I would emphasize that **ocean physics** and **undersea range and materials technologies** have traditionally been among our principal areas of excellence. NUWC and its predecessor laboratories have contributed significantly to fundamental knowledge in ocean physics. For example, key mechanisms which control the absorption of sound in sea water were discovered here.

Since the 1860's, with the start of the Torpedo Station on Goat Island, we have always looked at Narragansett Bay and surrounding waters as our undersea "laboratory." Today this real-world laboratory begins in the Gulf of Maine, where we do very limited, but highly valuable, torpedo testing in shallow water, and extends all the way to Long Island Sound, where we have a sophisticated Submarine Antenna Test Complex that is the best in the world.

With the recent emphasis on Naval Expeditionary Warfare to deal with regional conflicts, much of the focus in undersea warfare has shifted to supporting capabilities for joint expeditionary forces operating in littoral waters. NUWC technical efforts are reflecting this new emphasis on the shallow water of the littoral regions, and our technology development and evaluation programs require an increasing use of the shallow water areas and test facilities that comprise the Newport Littoral

Undersea Warfare Test Facility Complex. This unique complex consists of the following elements:

- Narragansett Bay Shallow Water Test Facility
- Shallow Water Diesel Submarine Target Facility
- Submarine Antenna Test Complex
- Narragansett Bay Operating Area Test Areas
- Gulf of Maine Test Areas
- Foxtrot Test Area
- Block Island/Fishers Island Test Area

IMPORTANCE OF OCEANOGRAPHY TO UNDERSEA WARFARE

In modern naval warfare, the performance of sensors is fundamental to mission success and to survival. Detecting and determining the location of a hostile submarine, torpedo, or mine at long ranges is key to survival and requires the best possible performance of our sonar sensors. The behavior of acoustic waves, used by most underwater sensors, is greatly influenced by local characteristics of the ocean medium and boundaries. Hence, there is a vital need for oceanographic information which allows reliable prediction of best operational techniques and interpretation of signals received. This is referred to as "tactical oceanography", and it is a field where there is a great deal left to be done.

NUWC has been working in this field for some time. For example, the first Navy oceanographer in space was a NUWC scientist, Dr. Paul Scully-Power, who flew on the Challenger in October, 1984, in order to conduct open ocean tactical oceanographic measurements

While our understanding of the open ocean environment is far from complete, we are even more challenged by the highly variable environments of the coastal zone, where water volumetric, surface and bottom characteristics each have a substantial impact on the performance of Naval missions.

The coastal waters of New England provide an excellent sampling of various coastal oceanographic conditions. There are diverse ocean bottom types; interior phenomena, including biotics, with large seasonal variations; and geographic situations with surrogate military applications.

REGIONAL PARTNERSHIPS:

While we have always had many informal relationships with educational institutions in New England, we have recently taken a much more aggressive role in forming partnerships, consortia, and coalitions. For example:

* NUWC is a charter member of the Ocean Technology Center (OTC) of the University of Rhode Island. Jeff Callahan will talk

in detail about those efforts. Just this month the OTC, with NUWC and a number of small companies as partners, won one of four awards for the "Ocean Technology Center of Excellence" in a statewide competition to establish centers of excellence. The focus of the proposal, which will now be going forward, is the development of technologies in the areas of marine foods, environmental monitoring, and ocean acoustics.

* NUWC, together with the University of Massachusetts, Dartmouth, was a catalyst for a consortium called MASSRICON (Massachusetts, Rhode Island, Connecticut). The members -

- Harvard University
- Massachusetts Institute of Technology (MIT)
- University of Massachusetts, Dartmouth
- University of Rhode Island, Graduate School of Oceanography
- Woods Hole Oceanographic Institute
- University of Connecticut, Avery Point
- Physical Sciences Incorporated
- Naval Undersea Warfare Center

- have formed an Industry, Government, and Academic team to build on regional strengths in ocean science. The focus of this group is to position the region to pursue an international enviro-tech market while addressing regional oceanographic interests, by leveraging regional intellectual and facility assets. Dr. Cressy will speak more about this subject.

* The Naval Undersea Warfare Center, Newport Division, has signed a five-year agreement with a nonprofit educational institution to help establish a marine park and learning center for children along the waterfront in New London, Connecticut.

NUWC's arrangement with OceanSciences, Incorporated is the Navy's first Education Partnership Agreement, an instrument authorized by Congress in 1990 to encourage defense laboratories to help local institutions promote science, math and engineering education. The New London park, called OceanQuest, will be the "marine equivalent" of the U. S. Space Camp in Huntsville, Alabama.

NUWC, Newport Division, primarily through its New London Detachment, will contribute scientific skill, facilities, equipment, computer software and other resources to OceanQuest's Science Adventure Center. OceanSciences, which is based in New London, will develop the educational materials for the center.

UNMANNED UNDERSEA VEHICLES:

As you heard at the beginning, NUWC's unique Navy laboratory mission includes the area of "autonomous undersea systems" - the primary example of which is Unmanned Undersea Vehicles, or UUV's.

UUV's offer the potential for revolutionary advances in undersea data gathering. Coincidentally, New England contains the greatest concentration of UUV technologists in the United States, working in various academic institutions, small and large businesses, and at the Navy's undersea technology laboratory.

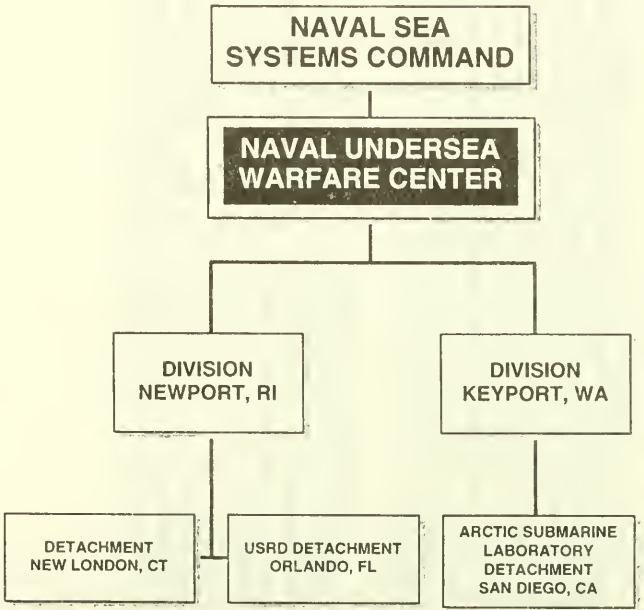
NUWC is the Navy's key resource in developing UUV technologies and vehicles. It has been aggressively pursuing advances in UUV propulsion, control, sensors, communications systems, and oceanographic mapping; and has demonstrated many advances in its adaptive vehicles. In addition to its own efforts, the Naval Undersea Warfare Center Division, Newport (NUWCDIVNPT) has established cooperative ties with academic institutions and some small businesses working on relevant technologies. In-water evaluations of their subsystem technologies are enabled using NUWCDIVNPT's Large Diameter UUV (LDUUV - 26.5" dia.) test vehicle in its Narragansett Bay test facilities.

The academic nucleus of UUV subsystems expertise in New England is very strong. Specific areas of technology advancement include Woods Hole Oceanographic Institution (UUV Low Speed Controller Models, High Data Rate Acoustic Communications Modems and Software), MIT (Novel Navigation Technique - Geophysical Map-based), and Northeastern University (High Data Rate Acoustic Communications Network Protocols).

Thus a special opportunity has emerged - to apply advanced UUV technologies for effectively achieving the goals of the MASSRICON consortium in the areas of fishery and coastal environmental data gathering/modeling verification. In addition, demonstrating these new UUV technologies would also support the five UUV focal projects being proposed in the National Research Council's *Undersea Vehicles and National Needs* study. The areas of required technological advancement - high resolution sensors, high data rate acoustic communications, advanced energy storage, non-traditional geophysical navigation, and UUV-based environmental sampling for models - could also have very significant applications in UUV's for military uses.

In summary, the Naval Undersea Warfare Center has a mission commitment to various aspects of oceanographic research, and is ready to expand its cooperative efforts with regional partners. The prospect of NUWCDIVNPT and its academic and industry partners demonstrating and applying new UUV technologies is especially promising. It would satisfy the need for intensive data gathering to understand coastal and fisheries phenomena in a time- and cost-effective way, a primary goal of New England's MASSRICON consortium. It would support the NRC National Needs effort in undersea vehicles and also help fulfill NUWC's mission by advancing the Navy's undersea warfare technology base.

NUWC



NAVAL SEA SYSTEMS COMMAND

NAVAL UNDERSEA WARFARE CENTER

DIVISION NEWPORT, RI

DIVISION KEYPORT, WA

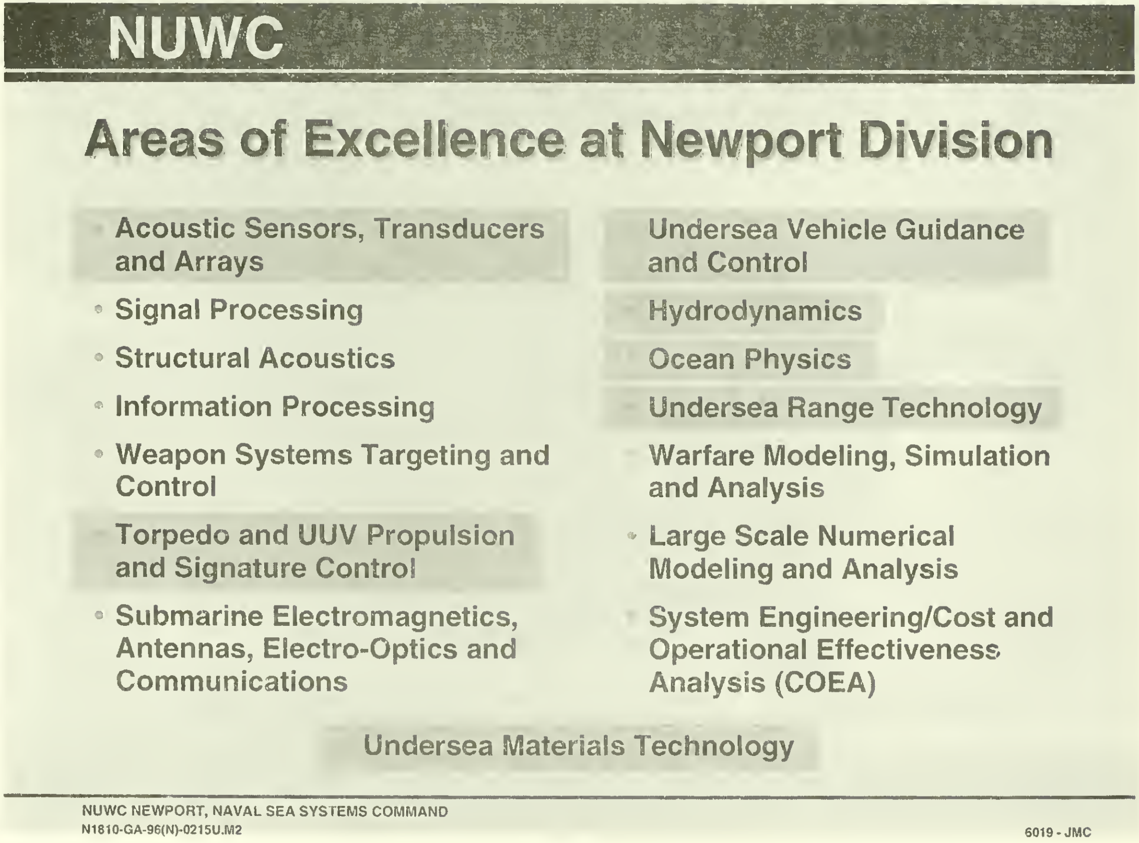
DETACHMENT NEW LONDON, CT

USRD DETACHMENT ORLANDO, FL

ARCTIC SUBMARINE LABORATORY DETACHMENT SAN DIEGO, CA

MISSION

Operate the Navy's full spectrum research, development, test and evaluation, engineering and fleet support center for submarines, autonomous underwater systems, and offensive and defensive weapons systems associated with undersea warfare



NUWC

Areas of Excellence at Newport Division

- Acoustic Sensors, Transducers and Arrays
- Signal Processing
- Structural Acoustics
- Information Processing
- Weapon Systems Targeting and Control
- Torpedo and UUV Propulsion and Signature Control
- Submarine Electromagnetics, Antennas, Electro-Optics and Communications
- Undersea Vehicle Guidance and Control
- Hydrodynamics
- Ocean Physics
- Undersea Range Technology
- Warfare Modeling, Simulation and Analysis
- Large Scale Numerical Modeling and Analysis
- System Engineering/Cost and Operational Effectiveness Analysis (COEA)

Undersea Materials Technology

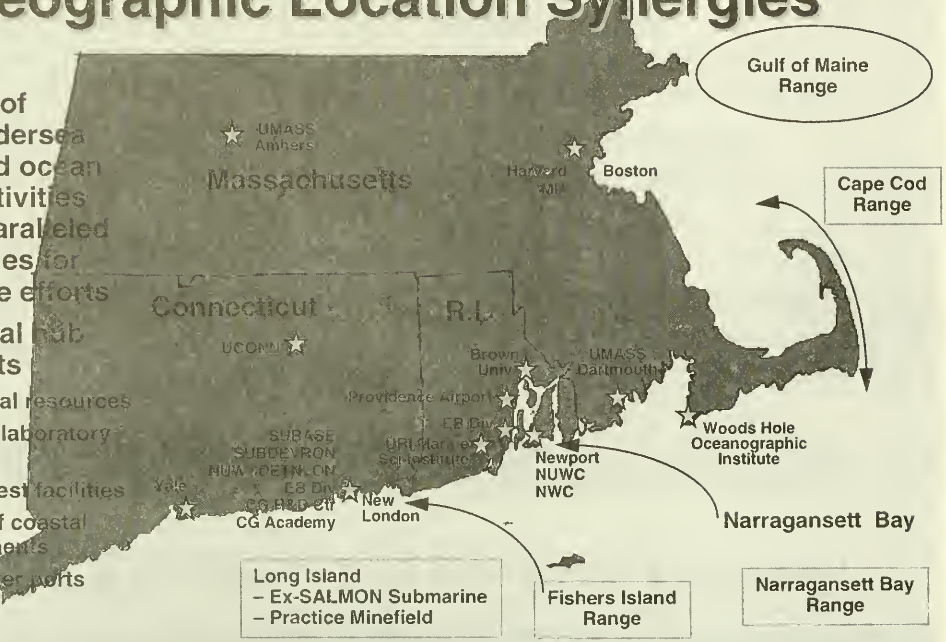
NUWC NEWPORT, NAVAL SEA SYSTEMS COMMAND
N1810-GA-96(N)-0215U.M2

6019 - JMC

NUWC

Geographic Location Synergies

- Clustering of diverse undersea warfare and ocean science activities yields unparalleled opportunities for cooperative efforts
- Key regional hub components
  - Intellectual resources
  - Relevant laboratory facilities
  - Coastal test facilities
  - Variety of coastal environments
  - Deep-water ports



NUWC NEWPORT, NAVAL SEA SYSTEMS COMMAND
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NUWC

NUWC Partnerships Relevant to Oceanography

Regional Partnerships

- Ocean Technology Center (centered at URI)
- MASSRICON Consortium (to build on regional strengths in oceanography)
- OceanQuest Science Adventure Center (Educational Partnership)

Unmanned Undersea Vehicle Technology Partnering

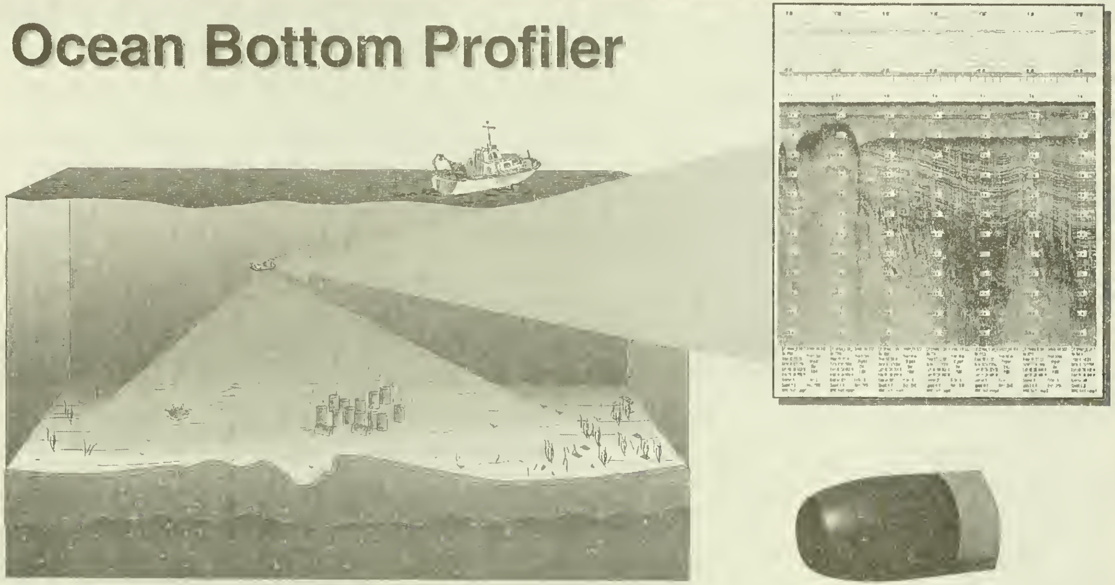
- Woods Hole Oceanographic Institution
- Massachusetts Institute of Technology
- Northeastern University
- Florida Atlantic University
- Pennsylvania State University
- Loral/Litton (Cooperative Research and Development Agreement (CRADA))
- Raytheon (proposed CRADA)

Torpedo Technology Spinoff

- Precision Signal, Incorporated - Ocean Bottom Profiler (CRADA)

NUWC

Ocean Bottom Profiler



Development of State-of-the-Art Sub-Ocean Bottom/Sediment Mapping Technology for Deep and Shallow Waters

NUWC, NAVAL SEA SYSTEMS COMMAND
N1810-GA-95(N)0309U.M13

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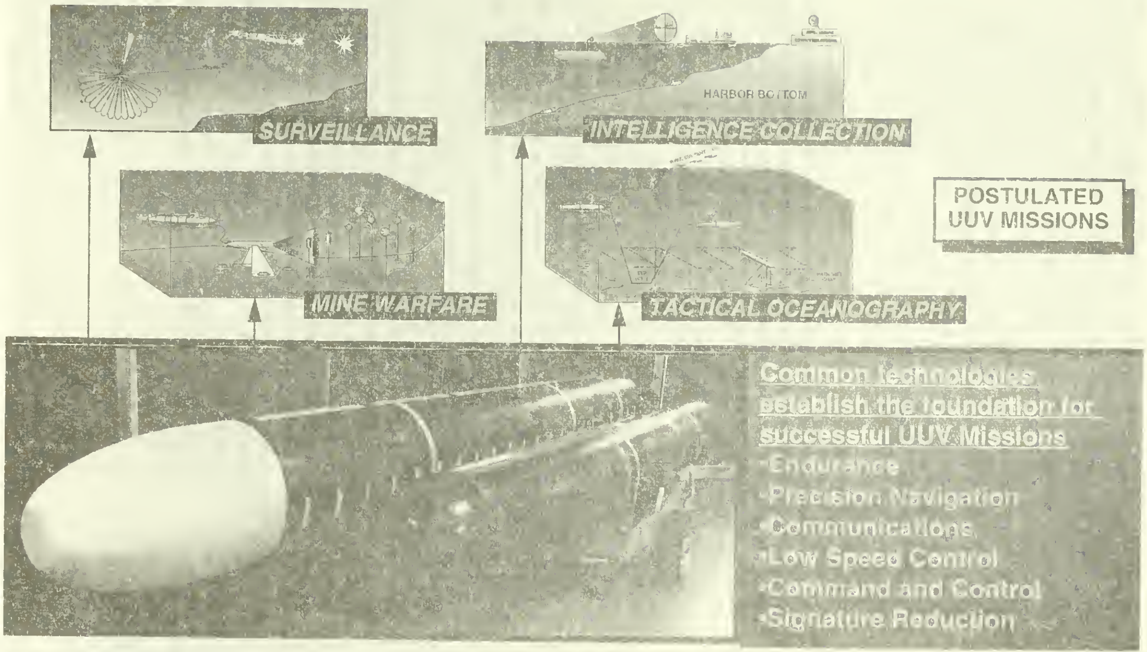
NUWC

UUV TECHNOLOGY DEVELOPMENT STRATEGY



SURVEILLANCE

INTELLIGENCE COLLECTION

MINE WARFARE

TACTICAL OCEANOGRAPHY

POSTULATED
UUV MISSIONS

Common technologies establish the foundation for successful UUV Missions

- Endurance
- Precision Navigation
- Communications
- Low Speed Control
- Command and Control
- Signature Reduction

NUWC DIVISION NEWPORT, NAVAL SEA SYSTEMS COMMAND

Developing the
tools for growth

RHODE ISLAND
ECONOMIC
DEVELOPMENT
CORPORATION

January 22, 1996

Committee on National Security
U.S. House of Representatives
Washington, DC 20515-6035

Dear Committee members:

I would like to thank the Committee on National Security for giving me the opportunity to speak on the important issue of economic development as it relates to oceanography, technology transfer, and research partnerships. The Rhode Island Economic Development Corporation continues to support the role of public investment in oceanography and ocean technology development. These important issues are deeply imbedded in the economic history of Rhode Island and must continue to advance thereby encouraging growth and expanding employment opportunities throughout all ocean and bay related sectors of commerce. I can't recall a time when the need for expanded ocean research activities were in greater demand here in Rhode Island.

The recent collapse of the New England groundfishery and defense spending cutbacks have had a significant impact on the Rhode Island economy. It is estimated that industries on Narragansett Bay alone provide $167 million in yearly wages and employ over eight thousand workers. Surprisingly, only 10% of these Bay related wages were generated through oceanographic related research. The declining budgets in oceanography and defense activity have certainly displaced a traditional workforce. Workers relying on the stability of defense contracting no longer have that job security. Therefore, the skills of our workforce have been utilized less with the decrease in defense funding and a strategy is necessary to keep the talents of those workers contributing to the economy of Southern New England.

Despite these recent restrictions, staff programs are in place to help mitigate the effects of such cutbacks and to become more proactive towards the resolution of these issues. I would like to bring to your attention examples of such programs recently partnered by the Rhode Island Economic Development Corporation (RIEDC). The Southern New England Marine Environmental Technology Industry Development Initiative addresses issues such as:

- Determining the regional technology assets of industry, academia, and government.
- Identifying the market gaps in Southern New England.
- Determining the cause and effect of successful or unsuccessful government programs;

7 Jackson Walkway
Providence
Rhode Island 02903

401-277-2601
Fax: 401-277-2102

- Identifying the critical barriers to job creation.

Programs like this, as well as the planned Marine Technology Loan Fund, provide opportunities for partners such as the University of Rhode Island's Graduate School of Oceanography (URIGSO) and the RIEDC to combine resources and proliferate extensive technical expertise in oceanography and other related sciences. The Marine Technology Loan Fund will be specifically targeted at entrepreneurs, business owners, and scientists to bridge the gap between marine technology development and commercialization. This may well be one of the most exciting tools we use. Unfortunately, this fund depends in part on an award of a grant from the Federal Economic Development Administration which is anticipated shortly but has not yet been confirmed. Since this program is targeted at precisely the sort of private-sector needs that other oceanographic programs will spin off, the synergy seems almost inevitable.

This type of synergy must be encouraged to occur across the bounds of industry, government and academia. We must continue to make use of Rhode Island's world class academic resources while uniting State and Federal agencies in their most effective roles for maximum results at minimum public cost. Towards completing this objective, we are cooperating with the efforts of Brown University, the National Aeronautic & Space Administration and Applied Science Associates to develop and commercialize satellite-based technology useful in analyzing marine resources. This project has the potential of moving a leading-edge technology from the laboratories of Brown into the marketplace, with the potential to create export-based jobs in manufacturing and technology services for Rhode Islanders. By starting with a comprehensive analysis of Narragansett Bay, the project will create a state-of-the-art tool for better management of Rhode Island's crowning resource. Resource maps generated through this process will be of value in planning for the protection of environmentally sensitive resources; targeting areas for more effective and sustainable economic uses; and identifying threats to the Bay as early as possible. This tool should prove especially useful to the State in pursuing Governor Almond's priority to reinvigorate and develop Rhode Island's aquaculture industry.

Perhaps in no other marine industry has this Country experienced a greater economic growth rate than in aquaculture. Despite the decline of groundfish fisheries in New England, the demand for seafood products has steadily increased. Aquaculture was reported in the *Rhode Island Commercial Fisheries Economic Adjustment Strategy* to be an approach by which it may be possible to mitigate the effects of a decreasing fishery on the states seafood industry. As we may already know, aquaculture is not a near term remedy for the over exploitation of groundfish stocks. However, it is a potentially powerful marine related economic sector in it's own right and can provide supplemental income to other sectors of the seafood industry and defense workers. The advance of oceanographic research will no doubt compliment the growth and expansion of this implicitly expanding industry.

The synergy of all the aforementioned programs are essential tools that will be utilized during the expansion and promotion of a sustainable aquaculture industry. For example, the programs mentioned today will facilitate the creation of use maps to designate aquaculture areas in State waters where usage will require minimal permitting. We are also currently looking at using a surplus military base at Quonset Point Davisville to determine if it can be used to support land based aquaculture. These partnerships will provide the environment in which entrepreneurs, industry, researchers, and government can foster the exchange of information and eliminate overlap. During the next decade, aquaculture is expected to remain among the top ten growth industries in the US and is currently the Nation's fastest growing agricultural business. Therefore, it is only logical that we continue to support marine research, development, and technology transfer to harness the benefits that this high potential high yield market offers. An overall strategy should emphasize marketing and economics to focus on researching further market potential as well as technology development focused on innovations in production technology, engineering, diseases, processing, and pollution prevention. One last important element of an efficient strategy is that the extension education for current and potential aquaculturists and educational extension services aimed at educating the public receive continued support.

A unique potential to address these issues lies within our borders. The Rhode Island Economic Policy Council has funded the University of Rhode Island's Ocean Technology Center to develop a concept plan for an Ocean Technology Research Center for Excellence. The goal is to establish a world-class organization of specific technology competency that demonstrates a direct economic benefit through university and private sector collaboration that results in commercial applications of the technology. Specific Goals of the program are as follows:

It will,

- Be driven by market forces, private sector competencies and institutional research skills.
- Leverage State dollars to attract industry and federal research funds.
- Increase Rhode Island's "opportunity share" in the realm of new industries, ideas, and products.
- Increase the role of research and technology in the Rhode Island Economy.

The concept plan will be a business plan for the initial startup of the Center and will include strategies for developing key skills, intellectual assets and specific technologies in areas which have potential economic benefit for Rhode Island. The Council has asked that each proposal include alliances and joint research projects between Rhode Island businesses and universities as well as other non-profit institutions including Federal research centers. One of the principle collaborators with the Ocean Technology Center is the Naval Underwater Warfare Center.

These programs will provide the interactive mechanisms allowing for increased opportunities in oceanographic technology transfer. National agencies will be better related to and therefore better able to respond to regional research and development needs. By supporting this exchange of information, regional technology developers and users can help define the national research agenda.

Finally, the programs that I spoke of today are but several initiatives of the Rhode Island Economic Development Corporation to react to the short term needs of the region. It will be through the planning efforts which these programs facilitate that the long term proactive solutions will be generated. Without the continued support of our federal agencies, it is unlikely that this State or our region will be financially able to sustain the policies and solutions which result from these ingenuitive programs. Therefore, I would have to believe that any contribution made from the Department of Defense towards the programs we have heard about today will significantly effect the future of this region's marine related economy. I urge the U.S House of Representatives National Security Committee to continue exploring the regional and national benefits of oceanographic research and technology transfer. The economy of this State and region have always benefited from the investment of defense and research dollars. For economic development to succeed in this region, a region inherently dependent it's marine resources, there is a distinct obligation for sustained support and realized objectives.

Sincerely,

Marcel Valois, Director

Opportunities and Regional Benefits from Oceanographic Research

David H. Reynhout
Manager, Submarine Signal Programs
Raytheon Electronic Systems
Portsmouth, RI 02871-1087

1/22/96

Good morning, Mr. Chairman, Members of the Subcommittee and staff. I am pleased to appear before you today to outline Raytheon views on the subjects of marine science and oceanographic research. These are areas of great importance both to my organization and to New England, in general. In fact, the Submarine Signal Operation of Raytheon Company traces its roots back to the Submarine Signal Company in 1901 - these matters have been important to us for over 90 years.

Today, I would like to address three topics to this group - one example of a technology which is particularly strong in New England but one which is suffering from declining budgets. One which fits our definition of dual use, but which has been entirely private sector financed. And, lastly, I'd like to address the subject of partnerships.

First, Unmanned Underwater Vehicles (UUVs) is an area also covered by Dr. John Sirmalis from NUWC, and whose remarks we strongly endorse. These torpedo-like devices which come in a variety of sizes offer numerous advantages to both military and commercial applications. To the military, functions such as covert surveillance and mine countermeasures can be accomplished without risk to human life.

Interest in the military applications led to a flurry of development activities in the early 90's with both DoD and industry investments, which in turn created a very strong base of technology centered here in New England among such organizations as Draper Laboratories, the Naval Undersea Warfare Center, Raytheon, Woods Hole Oceanographic Institute and others. However, government funding reductions have sharply reduced the number of military program opportunities. Attention of some of us was then diverted to commercial use of this technology.

Commercially, UUVs have considerable oceanographic research potential, as well as the ability to perform difficult underwater platform and pipeline inspections at low cost and in safety. Although we believe this technology holds significant promise in undersea applications, without government investment these commercial opportunities are reduced since potential users such as underwater pipeline operators do not typically underwrite product development. Without Government investment in industry, university, and government laboratory R&D, the risks are too high and the payback too uncertain for commercial interests to carry the development load.

So, although we've built a critical mass of capability in UUVs in the New England area, it is in danger of withering away.

I'd like now to discuss a dual-use development, which Raytheon has been engaged in along with our partner, Coastal Corporation of Houston, Texas.

The origins of this development go back to 1992. It was prompted by a confluence of events. The grounding of the EXXON VALDEZ in Prince William Sound, and the attendant damage; the

Oil Pollution Act of 1990 which resulted from that event; and a shared interest between Coastal Corporation and Raytheon in systems which could lead to safer oil tanker operation in shallow waters. OPA 90 states, in part (Section 411), and I quote:

> "Studies are required to...evaluate the adequacy of navigation equipment and systems on tankers including sonar, electronic chart display, and satellite technology...."

Based upon the above, Raytheon in partnership with the Coastal Corporation, has developed a system we call Automated Vessel Alert System, or AVERT. AVERT is a sonar system incorporating unique, patented signal processing techniques coupled with the use of digitized oceanographic chart data and satellite navigation. This system provides for operator alerts whenever the sonar detects underwater objects which are not charted, or which represent a possible hazard to safe navigation. Our market surveys indicated that there were a minimum of 1,000 80,000 and greater DWT tankers of less than 15 years age which could use such a system, together with some 300 military amphibious support, sea lift and cargo ships, and 300 large luxury cruise ships.

After having conducted feasibility testing on Raytheon's own research vessel, we initially approached ARPA during the early phases of the TRP process in 1993 and were enthusiastically received. Our subsequent proposal received letters of endorsement from NUWC, the U.S. Coast Guard Research and Development Center, the Oceanographer of the Navy, and the National Oceanographic and Atmospheric Administration and the State of Rhode Island proposed to invest matching funds. While not funded as a TRP project, Raytheon proceeded with Coastal Corporation to develop a prototype which was installed on MV COASTAL CORPUS CHRISTI and is operating successfully with considerable crew acceptance. We are convinced that AVERT can help prevent incidents such as EXXON VALDEZ, the QEII grounding in Cape Cod Bay and the grounding and fuel oil spillage of the Greek tanker off Newport on Brenton Reef together with the many other such accidents which occur routinely around the world. In fact, we are also convinced that once experience data has been gathered, insurance rates will reduce sufficiently to offset the cost of AVERT and its installation.

The shipping industry, however, is very cost competitive and may be loath to invest without incentives. We respectively suggest that it may be timely to revisit the provisions of the Oil Pollution Act of 1990 to determine whether stronger incentives for the installation of systems like AVERT should be encouraged.

Lastly, I would like to recognize the attempts by many of those who spoke to you today to achieve higher degrees of collaboration amongst the group of capable organizations in the region. And I'd like to preface this by being self-critical.

The capabilities, the technologies, and the talent are available in this region to be a world leader in the marine sciences. We could do much better if we were to take a regionalized, system-oriented approach to these partnerships, and to focus our efforts toward a grand objective. The partnerships we've participated in have been spiritually rewarding, and we want to continue to work in this manner.

We list the following partnerships among our successful collaborations:

- A partnership between Raytheon, Mass Maritime Academy and UMASS Dartmouth to develop a remote training capability and crisis management system for coping with environmental pollution spills in the ocean - successfully demonstrated.

- The URI Ocean Technology Center, a program where funds from industry paid memberships were matched by the National Science Foundation and used to support university researchers in areas of potential interest to the industry members.

- The Acoustic Partnership at URI between URI, NUWC, Raytheon and Marine Acoustics, Inc. - newly initiated effort to develop marine-related dual-use applications.

- The Ocean Technology Center of Excellence centered at URI with industry participation, a State of Rhode Island Economic Development Council funded initiative in the planning stage.

- Affordable Ocean Monitoring, a TRP proposal developed by Raytheon in teaming with The Charles Stark Draper Laboratory/Ocean Technologies, Inc.,/Battelle Ocean Sciences/Alupower, Inc./Woods Hole and Scripps Oceanographic Institutions/Texas A&M/Lawrence Livermore Laboratory re the application of UUVs to ocean environmental measurement.

But, I submit that we've been working tenderly around the edges and haven't addressed the larger role that a truly regional collaborative effort should be capable of. In that spirit, I heartily endorse the remarks of Dr. Cressy, and the notion of the Regional Technology Alliance. This comes closest in my opinion, to a truly system oriented approach to a regional alliance. This alliance should be funded by a Technology Reinvestment Program Grant, and focused on developing the coastal environmental technology industry as a meaningful place to start. I further recommend that a regional conference be convened to solicit participation of those organizations and individuals who can contribute toward forming the strongest possible program for New England and the maritime interests of the nation.

Comments Submitted by the URI Coastal Resources Center for the Committee on National Security Regional Briefing
Mahan Conference Center, Spruance Hall
Naval War College, Newport, Rhode Island
22 January 1996

Thank you for providing the Coastal Resources Center the opportunity to provide testimony regarding our perspectives on the issue of *Regional Opportunities in Leveraging Oceanographic Research for Defense and Non-defense Industries and Activities*

It is our hope/intention that this testimony provide the subcommittee members with the University of Rhode Island's Coastal Resources Center views on how leveraging technologies and partnerships, both in the United States and abroad can produce a mutually beneficial situation/relationship.

For more information contact Stephen Olsen, Director or Karla Boreri at the Coastal Resources Center, Marine Resources Building, Graduate School of Oceanography, Narragansett Bay Campus, Narragansett Rhode Island, 02881. The phone number is (401) 874-6224, ext. 6501 and the fax number is (401)789-4670. Thank you.

"The Nature of The Challenge"

1. Why coastal ecosystem's are of great importance and deserve the benefits of shared (applicable/relevant) US military resources, technology, and training capabilities.

- the coast can be defined as a ribbon of land 60 km wide containing a human population in 1990 as large as the entire planet's population in 1950 (Pernetta and Elder, 1993)
- this population is projected to double between 1990 and 2050 by which time it will include two-thirds of the world population (Merrick, 1989)
- an estimated 26 percent of all biological productivity, 5-10 percent of the world's food production and 85-99 percent of the world's catch occur in the coastal ecosystem (Postma and Zijlstra in Pernetta and Elder, 1993)
- yet, the world's coastal regions (which include the continental shelf) comprise only some 8 percent of the planet's surface (Holligan and Boois, 1993)
- clearly the coastal regions are increasingly the primary habitat of our (human) species (Olsen, 1995)

2. What are the issues of importance to collaborative efforts between the US military and organizations working in coastal ecosystems?

- tracking human population growth and human activities within the coastal region
- anthropogenic coastal ecosystem changes at all scales
- declining or collapse of nearshore fisheries
- mounting user conflicts
- inability of governmental organizations to avoid predictable adverse effects or mediate among conflicting groups

3. What types of activities could a partnership between the US military and such organizations as the CRC investigate?

- US leadership could provide an expanded scope of training both US and internationally, to include coastal management topics (i.e., monitoring of uses --fishing, tourism development, resource extraction, civil peace keeping, etc.,). In many developing countries (Ecuador as example) the Navy plays a central role in the monitoring, administration, and public policy aspects of coastal management.

US leadership could provide technical capabilities and expertise in the training of the use of monitoring, and mapping to both the US and international coastal management programs. Coastal management programs in the US and internationally could utilize military resources and technologies for activities including productivity patterns, global trends, date collection and analyzation including cause and effect (i.e., El Nino) and detailed mapping capabilities of coastal land-uses

For Example:
- A collaborative effort/partnership with US military technologies such as remote sensing, mapping could benefit a program such as the IOC Global Monitoring Program. This could be a potential partnership opportunity.

4. There are a number of partnerships that exist which could be nourished by collaborative efforts with the military (mapping capabilities, remote sensing, etc.,). The current partnership (with the US government, foreign governments, academic institutions and non governmental organizations) A list can be provided upon request.

(Not for publication until
released by the House
National Security Committee)

WRITTEN STATEMENT OF CAPTAIN ROBERT J. PLANTE
COMMANDING OFFICER
FLEET NUMERICAL METEOROLOGY AND OCEANOGRAPHY CENTER
MONTEREY, CALIFORNIA

CONGRESSIONAL FIELD BRIEFING FOR:

* House Committee on National Security, Subcommittee on Military Research and Development (Host)

* House Committee on Science, Subcommittee on Energy and Environment

February 12, 1996

(Not for publication until
released by the House
National Security Committee)

Good afternoon, Mr. Chairman and members of the Subcommittees. I am Captain Robert Plante, Commanding Officer of the Fleet Numerical Meteorology and Oceanography Center in Monterey, CA (more commonly referred to as "Fleet Numerical".) On January 25th, you heard testimony from several renowned scientists and senior executives, both within and outside of Government, who stressed the importance of the marine sciences to the nation's future. Two of the testimonies were presented by Admiral J. M. Boorda, Chief of Naval Operations, and Rear Admiral Paul G. Gaffney, Commander of the Naval Meteorology and Oceanography Command.

In his testimony, Admiral Boorda pointed out that "as an island nation, protected from adversaries and linked to partners by the world's great oceans, *it is fundamental that the United States understand the surrounding marine environment.*" He also explained that "Naval Oceanography embraces research, technology and operational programs not only in traditional oceanography, but also in meteorology, mapping, charting and geodesy, astrometry ... and precise time" as the nation's timekeeper. Admiral Boorda quoted the following recent Naval Oceanography policy statement: *"Understanding the oceans is fundamental to our national security as well as to global economic and environmental well-being. A robust competency in oceanography is a core requirement and responsibility of the U. S. Navy, one so vital to the success of our operations that we must lead in focusing national attention on ocean policy and programs."* He committed the Navy to "*encourag(ing) enhanced cooperation among the federal agencies, academia, industry, and international organizations in oceanography*". Admiral Boorda went on to describe the Naval Oceanography program structure in science and technology management as well as the operational oceanography program.

In the same hearing, my boss , Rear Admiral Gaffney also testified as to national oceanographic needs, partnerships, and the role of Naval oceanography. He pointed out that while "we are not specifically funded to help other non-Defense agencies to complete their ocean related functions, ... *we understand that we own and operate certain capabilities that can help others -- and we look for opportunities to make them available when it does not interfere with our primary mission or adversely impact our financial or security position.* Likewise, we will embrace proposals from other entities who wish to leverage their investments by partnering with us." Rear Admiral Gaffney further stated his commitment to "maintain a state-of-the-art computational capability to archive and analyze data and predict ocean and atmospheric conditions for the Department of Defense."

Deriving strong support from the Navy's science and technology program, Fleet Numerical is at the forefront of the Navy's operational meteorological and oceanographic capabilities. Specifically, Fleet Numerical's mission is to provide computer-generated descriptions of the air-ocean environment to the operating forces, anywhere, anytime. What do we mean by that? We are the U.S. military's principal processing center for computer-generated atmospheric and oceanic analyses and forecasts. As American and allied forces defend freedom, provide peacekeeping, deter aggression, and provide humanitarian relief across the globe from Haiti... Bosnia... Korea... Rwanda... Somalia... the Persian Gulf... Iraq... everywhere, the air-ocean environment is a factor. Overcast skies and storms in Bosnia which abort flights from aircraft carriers and land bases while bogging down ground transportation... heavy rains creating a quagmire for tanks and personnel carriers in the Iraqi desert... tropical cyclones threatening refugees in Cuba and peacekeeping operations around Haiti, and military operations in the Western Pacific and Indian Oceans... wind speed and direction determining the effectiveness of potential Iraqi chemical and biological weapons in the Middle East and their impact on American lives... ocean currents affecting mine locations and drift in the Persian Gulf and other water areas, and their potential devastating effect on shipping and international commerce... ocean thermal structure conditions which impact our ability to detect submarines belonging to potential adversaries, particularly the proliferation of diesel submarines in third world nations... these are all factors that Defense Department forces must deal with in real time DAILY.

Forecast accuracy can mean the difference between life and death, weapons effectiveness, mission success or failure. Fortunately, there are highly trained forecasters present with every military operation, some joint, some individual service, some on land, some at sea. All have the same needs - highly accurate computer-generated meteorological and oceanographic guidance products from which to develop an accurate, tailored forecast of the integrated air-ocean environment for military forces on-scene anywhere on the globe. *Fleet Numerical Meteorology and Oceanography Center in Monterey, California provides this essential service.*

Over the past several decades, Fleet Numerical has built one of the world's most elaborate air-ocean forecasting capabilities, with emphasis on the global oceans and the air-sea interface. Our ability to apply emerging technology to rapidly changing customer needs, while tailoring our computer-generated air-ocean forecasts to whatever part of the world constitutes today's immediate crisis, plus our unique global ocean analysis and forecast capability, all make us a singular national oceanographic asset. In fact, Fleet Numerical's uniqueness and value has been formally recognized by two "Federal Leadership Awards", one in 1993 and the other in 1995 *"for distinguished achievement in putting technology to work for government and the citizen".*

Fleet Numerical is the ONLY operational national or international center which produces real-time computer-generated meteorological and oceanographic information for the entire air-ocean integrated environment from the edge of space to the bottom of the sea. Our vast experience in oceanography, ocean data assimilation, and our expanding role in ocean forecasting is well known and respected in related scientific circles both nationally and internationally.

In today's financially difficult times, it is important to note that Fleet Numerical's services more than pay for its annual operating costs! Wind, seas, and ocean current forecasts provided for optimum track ship routing permit ship damage avoidance and fuel savings to the tune of tens of millions of dollars annually. A similar program for military aircraft routing saves comparable amounts of taxpayer dollars.

Although Fleet Numerical products are tailored for and primarily distributed to Defense Department customers, recent U.S. Government policies involving "dual use" and "technology transfer" have allowed an expanded distribution of the information we generate to the civil and commercial sectors as well. In 1994, the Oceanographer of the Navy and the Deputy Undersecretary of Commerce for Oceans and Atmosphere signed a memorandum of agreement "*to assure maximum efficiency in, and maximum benefit to, the United States from environmental data collection, analysis, monitoring, prediction and product distribution activities conducted cooperatively or jointly by (Navy and NOAA).*" Under an annex to this agreement, NOAA provides the conduit for distribution of Fleet Numerical products to the civil and commercial sectors, including private forecasting and ship-routing firms as well as schools and universities.

Another annex institutionalizes cooperative and joint efforts between Fleet Numerical and its civilian equivalent, NOAA's National Centers for Environmental Prediction (NCEP). Specifically, Fleet Numerical and NCEP back each other up as protection against catastrophic failure, share product output, and cooperate in the development of computer forecast techniques. In an example of mutual leveraging of scientific research and development, Fleet Numerical and NCEP are presently working cooperatively to develop a previously unavailable coastal ocean prediction capability. Complexities of differing coastal ocean environments require that each agency tackle a different part of the problem and share results. The benefit will be implementation of operational capabilities which meet the needs of both agencies, and at a cost much lower than if they developed similar capabilities independently. These capabilities will include significantly improved support for search-and-rescue, amphibious landings, U.S. Coast Guard support, drug interdiction, etc.

Beyond these agreements, a long history of cooperation exists between federal agencies involved with weather and ocean prediction. Today, in this era of declining budgets, changing military requirements, and increased demands for services, agencies are pursuing new areas of cooperation. This is particularly true for the nation's operational processing centers, which are capitalizing on improved computer and communications technologies to pioneer unprecedented collaborative efforts in the forecasting of meteorological and oceanographic phenomena. Today, these centers are highly interdependent components which can be applied to a broad range of national defense, economic and resource protection interests. The structure under which this cooperation takes place is through the Committee for Operational Processing Centers under the congressionally chartered Office of the Federal Coordinator for Meteorological Services and Supporting Research. Fleet Numerical is a major participant on this committee, which meets semi-annually to search for ways to cooperate on common problems. Subcommittees at the technical level then implement the full committee policy decisions for the common good of all concerned. In one example, the agencies involved (NOAA, Air Force and Navy) are presently expanding the mutual exchange of data by installing extremely high speed ("Asynchronous Transfer Mode") data links between their respective national centers. This effort represents an early Defense Department implementation of this burgeoning commercial technology.

Although originally formulated to address meteorological issues, the Office of the Federal Coordinator is now placing increased emphasis on the ocean. Over the last few years, the Operational Processing Centers committee membership has been expanded to include the Naval Oceanographic Office and NOAA's National Ocean Service in recognition of increased interest in ocean science and related issues.

The Shared Processing Program for remote sensing is another example of interagency cooperation. This program is a national effort which divides space satellite meteorological and oceanographic processing responsibilities between the major processing centers of this data. Partners in this program are the Air Force's Air Weather Service, NOAA's NESDIS, and the Navy centers at Fleet Numerical and the Naval Oceanographic Office in Mississippi. Under this program, Fleet Numerical has been designated the national Center of Expertise for microwave imagery deriving such products as surface wind speed, ice location and thickness and rainfall rates from spaceborne sensors. As pointed out by Rear Admiral Gaffney in his January 25th testimony, the two Navy sites collectively contribute a full spectrum of remotely sensed ocean parameters (winds, seas, ocean surface temperatures, altimetry, sea ice, etc.) to the national data bank repository of remotely sensed information. This data is then available for both operational and historical use, within government and in the private sector. Additionally, Fleet Numerical pioneered the establishment of algorithm research panels. These panels provide a mechanism to reach out to not only government laboratories but to universities as well in seeking to improve the quality of satellite derived products.

My presentation to this committee would not be complete without sharing with you the partnerships and interactive mechanisms that are in place both inside and outside of Government on California's Monterey Peninsula. There, the unique niche that Fleet Numerical Meteorology and Oceanography Center fills in the area of air-ocean coupled modeling and global product distribution to both military and civil sector users has helped to evolve a burgeoning "region of excellence" in the marine sciences. This "region of excellence" has come together due to major thrusts in three areas of scientific synergism - education, research and operations.

On the education side, the Naval Postgraduate School's Meteorology and Oceanography Departments go back to the early 1950s. Fleet Numerical first located in Monterey in 1959 to take advantage of the school's scientific talent and its ownership of one of the earliest second-generation mainframe computers. Today, we not only have strong ties with the meteorology and oceanography departments, but with computer science, information technology and operations studies departments as well. Other Marine Science graduate programs have been developed in the Monterey Bay area under the auspices of Stanford and San Jose State Universities, and the University of California at Santa Cruz. Today, a new educational institution, the California State University at Monterey Bay, is being built from the ground up as a 21st century campus on the former Fort Ord Army Post. This new university will feature major programs in oceanography and meteorology. It opened in August 1995, and enrollment is expected to approach 25,000 students in the next century.

On the research side, the Naval Research Laboratory (NRL)'s Marine Meteorology Division moved to Monterey from Norfolk, VA in 1971 to collocate with Fleet Numerical and the Naval Postgraduate School. This division of NRL is responsible for developing the computer-generated atmospheric and coupled air-ocean predictions which are then implemented operationally at Fleet Numerical. The division's collocation with Fleet Numerical significantly streamlines the process of transitioning these computer programs from a science and technology to an operational environment, and facilitates the correction of any science shortcomings and/or software errors once operational.

In 1969, the first interagency collocation occurred when NOAA's National Marine Fisheries Service established a small contingent at Fleet Numerical called the Pacific Fisheries Environmental Group. This was done in order to apply the Navy's information on the marine environment to the nation's fisheries issues. This Group is the single laboratory in the Fisheries system that focuses on comprehensive assessment and understanding of the fundamental effects of natural environmental variability on marine living resources. The close relationship between the Fisheries Group and Fleet Numerical includes ocean data exchange, and use of Fleet Numerical's real-time products and archived historical data for fisheries research. The NOAA Fisheries Group is thus able to use Navy oceanographic information to enhance the international competitiveness and productivity of our nation's fishing industry.

On the marine science side, the Monterey Bay Aquarium Research Institute was established by the Packard Foundation in the mid 1980s as an adjunct to the new (now world renowned) Monterey Bay Aquarium. Additionally, a new research center focusing on marine sciences and the environment is also being established on the former Fort Ord Army Post. It is being developed under the direction of the University of California at Santa Cruz. This center, known as the Monterey Bay Science and Technology Center, will be a true partnership between academia and industry with full cooperation from related government agencies.

The operational side of this scientific synergism has focused primarily on Fleet Numerical for most of the past 35 years. However, over the last decade, NOAA has shown an increasing interest in the cooperative benefits of collocation. In 1985, a component of NOAA's National Ocean Service was established on the Fleet Numerical compound to act as a conduit to provide Navy meteorological and oceanographic data to the civilian sector. In 1994, the National Weather Service relocated its Northern and Central California Forecast Office from the San Francisco Bay area to a location immediately adjacent to Fleet Numerical in Monterey. This was done in part because of NOAA's desire to collocate its Weather Forecast Offices with institutions of higher learning in the air-ocean sciences where possible, and in part to the opportunity for collocation with the Navy and other NOAA activities. Interestingly, this Forecast Office is one of the few with oceanographic responsibilities in support of civil interests, thus the synergism from collocation is indeed beneficial operationally. This relocation to Monterey has already resulted in the availability of additional shared information and capabilities among the several collocated organizations, and has provided new educational and research opportunities for Weather Service personnel at the nearby Naval Postgraduate School.

Mr. Chairman, I have taken this opportunity to expound on the January 25th remarks of Admiral Boorda and Rear Admiral Gaffney in order to describe the unique role Fleet Numerical plays in the nation's defense, and in its capability to help develop and contribute to academic/government/industry partnerships. I have further shared with you the synergistic relationship that is blossoming on the Monterey Peninsula in the form of a Center of Excellence in Marine Sciences. Mr. Chairman, I have appreciated the opportunity to present this testimony. We look forward to the visit tomorrow of your staff personnel, in order that they may see this synergistic cooperative effort in action.

CONGRESSIONAL FIELD BRIEFING: REGIONAL OPPORTUNITIES IN LEVERAGING OCEANOGRAPHIC RESEARCH FOR DEFENSE AND NON-DEFENSE INDUSTRIES AND ACTIVITIES

February 12, 1996

Distinguished Members of Congress

My name is James Kennett and I am a Professor of Oceanography in the Department of Geological Sciences and Director of the Marine Science Institute at the University of California Santa Barbara (UCSB). I am pleased to testify in this west coast field hearing concerning the future of marine science research. As a member of the local community, I welcome Committee Members and Witnesses to our area. Much of our local economy and quality of life is related to the proximity of the ocean, and reflects the community's desire to manage this asset in a scientifically and socially responsible way. UCSB has a large and very active marine research and teaching program which is fitting for a University campus which is the only full-spectrum university in the United States that is located on the open-ocean. We are also linked through consortia and other mechanisms with extensive marine science programs conducted on a number of the campuses of the University of California (including Scripps Institution of Oceanography), which surely must make the University of California the largest academic marine science and teaching enterprise in the world. There are other important connections. UCSB is pleased to be a member of the Consortium for Oceanographic Research and Education (CORE), which is a broad and large partnership of this nation's academic marine programs and is beginning to play a major leadership role in marine sciences in this nation. In fact I am happy to report that UCSB is a member of the first regional group to join CORE in cooperation with UCLA, UC Irvine and UC Santa Cruz. Our research programs here at UCSB range through a broad spectrum of marine science but I shall be able to mention only a few. Additional information about our program is provided separately.

University faculty know that research and teaching are closely intertwined. To attain the best results, students must experience a superior, stimulating and exciting intellectual environment. It has been stated that, "the university lives on the research of its faculty and the learning of its young. The university looks to the future, cares for the future, works for the future. By counterpoising the experience and fatigue of its faculty against the energy and innocence of its students, it almost invisibly reshapes the republic in the minds and hearts of the young." Research prospers at universities because, not in spite, of its educational role.

Our teaching program in marine science at UCSB involves large numbers of undergraduate and graduate students and is connected with a strong and diverse marine science research program. This morning I gave a lecture to more than 200 undergraduate students in a general education course on oceanography. Marine science courses are very popular with our undergraduate students. In fact more than half of all graduating students at UCSB have taken at least one course in marine science. This amounts to thousands of students per year. Why do our students take courses dealing with the ocean? The main reason appears to be because young people are very interested in the ocean environment and its life, and sense the great importance of the ocean's role in their destiny; its role as a major player in the global environment, the global economy, security, and as a frontier zone of discovery. Undergraduate students also work as apprentices in many of our marine science laboratories. Currently we have 138 undergraduate students employed in laboratories associated with the Marine Science Institute (MSI). Also we have more than 100 graduate students at UCSB working on marine-related research problems. The extent of this activity seems to reflect the public's insatiable appetite for knowledge about the ocean; also reflected by an on-going proliferation of marine aquaria in this nation and the world. In this regard, each year at MSI we guide more than 7,000 school children on tours through the university's sea-water facility and biological holding tanks. This is one of the university's most popular public outreach programs and has required a lottery to help regulate the strong demand. In these and related teaching programs we have discovered that our marine science education programs have been effective in helping students nurture interest in science.

Why study the oceans? Why should society support research in marine science? I believe this is important because the oceans are becoming increasingly linked to the great future challenges that currently face human beings. What will be the big issues facing society in the 21st century? I believe that the most important challenges facing society in the next century will be those resulting from extremely rapid human population growth and associated industrialization. This will severely test global resources and the related integrity of the global environment and biosphere. Also tested will be the existing social order. The ocean will become increasingly important in these key future issues. The ocean is the dominant feature of Earth; it covers 72% of the Earth's surface, constitutes more than 90% of the habitable space for life, and contains critical food and mineral resources. Our weather, in large measure, is formed and strongly modified over the oceans. The ocean exerts truly enormous control over the global climate system. The Pacific and Southern Oceans are particularly important in this regard. The people of the United States have developed a strong affinity with the ocean. More than 50 percent of the U.S. population lives within 50 miles of the ocean and the Great Lakes. Human populations throughout the world cluster close to the ocean. The oceans are very important in international transportation especially related to trade. Increasing efficiency in marine transportation in international trade has played a key role in the expansion of the global economy. Further, the apparent shrinking of our planet has led to greater importance of the ocean with respect to national and international security, and hence of increasing importance to the military. The U.S. Navy has always had a close relationship with the oceanographic community, with the attitude that new basic knowledge about the ocean automatically strengthens the Navy's mission. With the end of the Cold War, the Navy is entering into a new phase of sharing its formerly classified facilities with unclassified academic researchers in the same spirit.

Yet in spite of all these factors, the ocean remains inadequately described and poorly understood as a system. Ignorance about our oceans translates into major ignorance about our planet. In spite of major advances since 1950, the ocean remains a major frontier in science. Much of the ocean environment is remote, cold and dark. It is not an easy environment to work in and on, especially if you get seasick! Its workings are poorly understood. It is not a simple system and interacts in complex ways with the other components of the Earth system. For the first time, the Earth is being studied by scientists as a system of closely integrated components. Science and Technology have now evolved sufficiently to begin to unravel the complex processes that dominate the life-sustaining Earth, including how human activities may influence change. The Earth is a linked system - change one part and another part is changed. However, much ignorance remains about such linkages and feedbacks and about processes that control weather variability, climate change on various time scales, global change in the geological past, ocean sediment processes and associated mineral and hydrocarbon resources on continental margins, and the processes that govern biological cycling in the ocean. In effect, we need to better understand the role of the ocean and its marine biota and their role in the Earth system.

Marine scientists at UC Santa Barbara continue to contribute toward better understanding of our ocean and the related workings of our planet. We are able to work in a remarkable natural marine laboratory right on our doorstep. The marine environment of the Santa Barbara Channel and California Current system is providing us with an astonishingly clear window to view the workings of the global ocean and climate system. It appears to amplify global signals. Investigations by campus scientists working in this natural laboratory are leading to important and exciting discoveries. For example, we have recently discovered in the drilled sedimentary record of the Santa Barbara Basin (drilled by the Ocean Drilling Program), evidence for many major, rapid sea-surface warming events in the recent geologic past that occurred within human life spans. These correlate with similar rapid warming events recorded in the Greenland Ice Sheet on the other side of the globe. Our results suggest a high sensitivity of the vast Pacific Ocean to change in the global climate system. Considerable energy was required to cause these rapid warming events. We believe that we have discovered the cause of these rapid warming events; i.e., where this energy came from. Our geochemical results suggest that the warmings were possibly caused by major releases of large volumes of methane (natural gas) from ocean sediments on the continental margins due to the melting of gas hydrates, or clathrates, frozen within the sediments. At the relatively high pressures in the ocean, a mixture of methane and water freezes at particular ocean floor temperatures. Our data suggest that the ocean periodically burped methane, leading to rapid greenhouse warming. This work is new and surprising and our hypothesis remains to be independently tested and verified. We discovered these features first because the Santa Barbara Basin sediment record acts as a powerful telescope aimed at the marine climate record. Our results also highlight the fact that we still know little about major processes occurring in the ocean and interrelations with the Earth system. Expect major surprises in the future!

Our work also helps highlight the importance of clathrates as an enormous, but poorly known energy resource. Clathrates store large volumes of organic carbon. Estimates of the total amount of organic carbon stored as methane in clathrates is 11,000 Gigatons, which is more than double the known reserves of all fossil fuels in the world! Given that clathrates represent such an important potential future energy source, I have been surprised about how little is known about them. I need to mention that the Ocean Drilling Program (ODP) has provided important assistance. ODP, an international effort, led by the United States, is one of the largest and most successful earth science programs of this century and certainly the most successful international program. This program forms an important technological interface between Academia and Industry. Resulting data has led to enormous advances in knowledge about how the Earth works, and this is important to the Industrial sector.

The richness of hydrocarbons in marine sediments of this region of California is well known and results from a particular combination of geological and oceanographic conditions. Because of this, our local natural marine laboratory also provides important opportunities to study processes involved in the formation of hydrocarbons in a modern setting. On the other hand, the local situation also provides unusual opportunities to study the effects of multiple oil production platforms on the marine environment. This is a highly contentious issue with little scientific evidence to sort out fact from fiction! We have programs at UCSB that are studying this problem. These programs are being carried out by groups involving Industry, the University of California, the State of California and the Department of Interior. Such cooperative programs involving universities are clearly productive ventures and we need more of them to obtain useful answers to pressing problems. Because of the historic environmental measures that have had to be taken concerning the local offshore oil platforms, Santa Barbara is now a world center for the export of offshore oil pollution advice and technology. This has developed into a viable commercial industry in itself.

Scientific discoveries by UCSB marine biotechnologists and pharmacologists during the last two decades supported by the Sea Grant Program have led to successful technology transfer between the academic and commercial worlds. One example is the discovery of anti-inflammatory drugs for medical use. Other discoveries have assisted with the development of the abalone aquaculture industry. The discovery of chemical cues that induce spawning and progressive life development (metamorphosis) in abalones have been vital in the development of an economically viable commercial abalone industry here in Southern California. This developing industry now accounts for revenues of millions of dollars annually. The fishery is also important because of the severe depletion of the wild stocks of abalones at a time of increasing consumer demand. These discoveries represent small but important beginnings towards economical utilization of ocean materials.

As a result of continued environmental disturbance by human activities, increasing needs exist for determining ways of mitigating adverse effects resulting from anthropogenic activities on coastal marine resources. Environmental degradation leads to resource degradation which in turn can lead to economic degradation. The largest present day commercial fishery in California is based on red sea urchin gonads. Continued viability of this urchin fishery depends upon healthy kelp production since the urchins feed almost entirely on this algae. Researchers at UCSB continue to investigate kelp biology and have important to the agricultural industry. Although by no means solved, excellent beginnings have been made in understanding such changes in the climate system. The Insurance Industry has become very interested in ocean storms, especially hurricanes.

In closing, I wish to say that I believe that much stronger linkages must be developed between scientists and congressional policy makers. Sound policy decisions should be based on the best available scientific information. However, environmental change is occurring rapidly and with the grim prospects of world population increase, the pace will continue to quicken. Sound policy requires the best available scientific concepts and data which take time to generate. It is critical that these are produced ahead of time to assist with policy decisions. As I have mentioned earlier, the ocean is the sum of a complex interplay of various components that are linked to other parts of the Earth system. Study of the ocean thus requires much closer partnerships between the public, their congressional representatives, government and state agencies, universities and industry, all of which bring valuable and vitally different perspectives to the overall understanding of the global environment. In certain cases this should be expanded to the international community such as illustrated by the Ocean Drilling Program. The Ocean Drilling Program after all has taught us, amongst many things, that we live on a planet that has constantly undergone dynamic change.

The United States has been the world leader in marine science research since World War II, and this has led to a remarkably rapid increase in the understanding of the oceans. There has been a marked decrease in the last 15 years in the funding levels (in constant dollars) that support marine science research in this nation. The oceans are far too important economically, environmentally, culturally and aesthetically to seriously impair further understanding. The nation must not continue to erode its science and technology base. It is difficult to predict future directions in science, especially that related to resource utilization, conservation and the economy of the nation. However it is crucial that the United States does not export its current leadership role in ocean research.

James P. Kennett
Marine Science Institute and
Department of Geological Sciences
University of California Santa Barbara
Santa Barbara, CA 93106
(805) 893-3764
Kennett@msi.ucsb.edu

WRITTEN STATEMENT OF

ARTHUR U. AYRES
CHIEF OPERATIONS ENGINEER
VICE PRESIDENT
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

BEFORE THE JOINT HEARINGS

SUBCOMMITEE ON MILITARY RESEARCH AND DEVELOPMENT
COMMITTEE ON NATIONAL SECURITY
U.S. HOUSE OF REPRESENTATIVES

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

12 FEBRUARY 1996

The MariPro Operation of Science Applications International Corporation is involved in the design, manufacture and installation of a wide range of systems for military, scientific and commercial customers. These systems are ocean based and consist of cables and various sensors installed in water depths from deep abyssal ocean to shallow littoral. As examples, they include a Training Range for the Navy, the acoustic source installation for the ATOC program and the communications system from Pt Mugu to San Nicolas Island.

The Fleet Tactical Training Range installed at San Clemente Island provides the Navy a 200 square nautical instrumented facility to provide the accurate three dimensional location of underwater participants in Naval training exercises. This range consists of 8 cabled arrays running from shore to sea. Each array has 8 hydrophones separated by one to two nautical miles and a trunk to the beach landing. The program required the hydrophones to be placed on the bottom with an absolute accuracy of better than 100 meters in water depths of up to 2000 meters. The planning for this system included a design compatible with the installation requirements and an installation procedure to provide the required placement accuracy. Historic data provided general bathyemetery and very limited ocean current data. This was adequate to establish the general approach to the installation. However, bathyemetry over each of the cable runs was acquired to establish the detailed cable deployment schedule. A major problem in this type of installation is knowledge of ocean current profiles at the time the cable is being deployed. This was accomplished by using a pair of doppler current meters in real time. One was installed on the installation vessel and the towed near the bottom. This approach worked, but limited the installation to speeds less than one knot exposing the system to up to 60 hours of risk due to changes in the weather. Weather forecasting played a critical role in the program. More detailed knowledge of the expected ocean current in the area and its variability could have eliminated the need for real time current measurements and allowed installation at higher speeds. This would have significantly reduced the cost of the installation and reduced the risk of system damage or loss due to changes in the weather. The availability of long term current data in the San Clemente area could possibly be of benefit to the Environmental community. A measurement program was undertaken by MMS in the Santa Barbara channel several years ago to provide data on the transport of oil in the area in case of a major spill. This data base was limited to the specific requirements of MMS. Whether or not there could have been an overlapping program to include the Navy requirements is not known. However, there appears to be a possibility that joint regional planning between agencies with vastly different charters could have saved in the overall cost of both programs.

The Acoustic Thermometry for Ocean Climate (ATOC) program will provide long term temperature measurements of the Pacific Ocean to establish the trend of global temperature. An acoustic source was installed on a sea mount off the coast of Northern California at Pillar Point. The installation required a detailed knowledge of the bathymetry from the beach to the installation point. Since the projector was to be installed on the sea mount, the requirements for accurate navigation and depth measurements were stringent. The site was surveyed using a precision depth recorder and differential GPS navigation. As in the San Clemente installation, accurate predictions of weather and sea conditions over periods of several days was required. The penalty for poor depth data, navigation or weather prediction is the loss of expensive and difficult to replace equipment.

Communications between the mainland and San Nicolas Island play a vital role in the development and test of Naval Systems. The microwave system in use prior to the installation of the fiber optic cables provided limited and marginal communications. The FOCUS program replaced microwaves with a 1.2 Gb/s optical system with significantly more capacity and reliability. The installation required sea to shore interfaces at both Pt Mugu and San Nicolas Island. These interfaces were constructed using reconditioned drill pipe as a conduit for the cable. The design of this protection required estimates of sand transport, depletion during winter and replacement in summer. Some data was available, but coordinated data bases from the many programs studying this area would have made the design process more satisfactory from an engineering standpoint and would have reduced the risk of system damage during its 25 year service life. The cable route from the mainland to the island was planned using standard bathymetric charts. These gave a general indication of depths and slopes. Prior to the cable deployment, a detailed survey was accomplished using a precision depth recorder and differential GPS as a navigation aid. This data, along with data collected by the Navy provided the data base for the program. This data was not coordinated with NOAA or any other agency. Whether or not this would be a useful thing is not known. However, large amounts of data are collected for many programs. If this could be coordinated, it might reduce the need for other collection programs.

All of the described programs use ships of opportunity for the at-sea work. Since dedicated vessels require operation and maintenance cost beyond the scope of current programs, SAIC has developed a containerized installation system. The elements of this system include the cable hold back machine and its power pack, cable splicing and navigation vans. These units use standard ISO containers or container form factors allowing them to be shipped as standard ocean freight. In most markets a wide range of ships are available for charter at day rates. These are normally off-shore oil supply boats with large un-obstructed after decks. The containers are designed for rapid mobilization. This permits the conversion of a vessel to a cable layer in 24 hours. This concept can be used for a wide range of oceanographic missions.

The interaction between Oceanography and the SAIC ocean system business is primarily in the area of data sets relating to bathymetry, current profile and bottom characteristics. During the design of these systems, accurate and complete data would speed the design process and reduce the risk of failure during the installation phase. Data is available from a wide range of sources, but it is difficult to assemble and apply under the pressure of tight schedules and limited budgets. A possible solution to this problem could be the availability of "consultants" within the oceanographic community who would be available, along with well organized data bases, to both military and commercial programs. These sources, whether they be government or academic, of design data could be included in DOD procurements. Commercial programs would pay for these services as required. Since both military and commercial programs are driven by cost, these data sources would have to be efficient and directly applicable to the specific design problem.

The SAIC to Oceanography interaction appears to be some formalization of our data collection for specific programs to make them applicable for other uses. As an example, the collection of bathymetric data for a cable installation could be used by NOAA in the generation of more accurate bathymetric charts and data sets. To be useful, the data would have to meet the quality requirements set up for these uses. This requires the establishment of requirements at the beginning of government sponsored programs or the development of payment schedules for data generated by commercial programs.

As in all endeavors, the most difficult problem is one of coordinating diverse programs over extended periods of time to meet well established goals. If the requirements of the Oceanographic community could be generalized and made known to the other elements of the ocean community, there is a possibility that a program to share the collection of data could be established. This could reduce the need for specific programs and provide more complete data to the designers of ocean systems. This would provide not only a direct reduction of the cost of collecting data, but provide savings in the cost of systems through the reduction in the risk of failure while working at sea.

Testimony of Dr. John Orcutt

Director, Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
University of California, San Diego

Before the
House National Security Subcommittee on Military Research and Development
and the
House Science Subcommittee on Energy and Environment

February 12, 1996

Mr. Chairman and members of the subcommittees, thank you for this opportunity to discuss the future of oceanographic research. I am Dr. John Orcutt, Director of the Institute of Geophysics and Planetary Physics at Scripps Institution of Oceanography (SIO). I am representing Dr. Edward Frieman, Vice Chancellor of Marine Sciences at the University of California at San Diego (UCSD) and Director of Scripps Institution of Oceanography. Dr. Frieman regrets that he is not able to participate in this important briefing. On behalf of Dr. Frieman and my colleagues at SIO, I want to express our appreciation for your interest in the future of oceanographic research. I also want to thank Admiral Watkins, President of the Consortium for Oceanographic Research and Education (CORE), for his leadership on this issue.

I have been going to sea for nearly three decades. First as a submariner in the U.S. Navy and later as a marine seismologist studying volcanic mid-ocean ridges. My experience in the Navy heightened my awareness of the importance of understanding ocean processes for national security. Strong federal investment in oceanography since World War II enabled our country to meet the challenges of the Cold War. I am concerned, however, that mission agencies (Navy, NASA, NOAA, DOE) are decreasing their support for discovery research and thereby undermining our capacity to meet the challenges of the next decade. Many of these challenges demand the resources and capabilities of the ocean science community. Strengthening the partnership between the oceanographic community and the federal government is essential to our ability to expand and master new frontiers.

Scripps Institution of Oceanography was built through a series of partnerships–with the Scripps family, the State of California, the University of California and later with the Navy, NSF and other federal agencies. During World War I, Scripps began several large-scale cooperative projects with the State and federal government, initiating a practice that we continue today. I will begin my testimony with an overview of Scripps to illustrate what can be built through partnerships. I will then focus on our special partnership with the Department of Defense. I will spend the rest of my testimony discussing one of the most critical issues for the future of U.S. Oceanographic research–the health of the academic fleet, or if you prefer–the "ships" in "partnership."

OVERVIEW OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

From our campus overlooking the Pacific Ocean, Scripps Institution of Oceanography (SIO) continues a more than 90-year tradition of scientific leadership. This leadership was developed by sharing intellect, experience, data, instrument development, facilities and labor with the State and federal government. SIO is one of the world's oldest, largest, and most important centers for marine science research, graduate training and public service. Part of the University of California at San Diego, SIO's preeminence in biological, physical, chemical, climatological, geological, and geophysical studies reflects its continuing commitment to excellence in research, modern facilities, distinguished faculty, outstanding students, and the continued support of the State and federal government. Acknowledging our rich tradition, the National Research Council recently ranked SIO first in faculty quality among oceanography programs nationwide.

With annual expenditures of more than $100 million and a staff of 1,200 scientists, technicians and support personnel, including nearly 200 graduate students, SIO is involved in more than 300 major research programs. There are many examples of successful oceanographic partnerships at SIO. For the record, I am including overviews of some of these projects which you may find of interest. These partnerships demonstrate the practical value of investing in ocean research.

SIO also maintains the largest fleet of academic research vessels in the country with 4 sea-going vessels, including the Roger Revelle (AGOR 24) which was launched on April 20, 1995, and two research platforms. SIO has operated both large and small world-ranging ocean science research ships continuously since 1908 for the use of all U.S., ocean-going researchers.

The success of U.S. oceanographic research and the growth of institutions such as Scripps are due to the financial support from federal and State agencies. In FY 1995, SIO successfully competed for more than $100 million in federal funding: nearly $30 million from the National Science Foundation; nearly $30 million from the Department of Defense (primarily the Office of Naval Research); $17 million from the National Oceanic and Atmospheric Administration; more than $6 million from the National Aeronautics and Space Administration; $4.5 million from the Department of Energy: and approximately $5 million from other U.S. government agencies (MMS, NIH, USGS, State Department, and the U.S. Forest Service). SIO also received $18.5 million in support from the State of California and $3 million in private gifts.

The success of SIO also depends on the quality of its students. More than 70% of SIO graduates become faculty members at universities around the world. Scripps graduates are also represented in ministerial and advisory positions in a number of governmental agencies within the U.S. and in other countries.

SIO & NATIONAL SECURITY

In FY 1995, SIO successfully competed for nearly $30 million in Department of Defense contracts and grants. This work continues the more-than 50-year partnership between the Department of Defense and SIO. Through this partnership, DoD and SIO scientists have advanced the frontiers of knowledge of the world's oceans and developed technologies necessary to maintain national security. Our nation is bordered by oceans, thus maintaining control of these oceans, including the development of a full understanding of ocean processes and related technologies, is critical to national security.

During World War II and continuing today, the DoD has used University-developed knowledge to gain and maintain its operational and technological lead over all other nations. With the end of the Cold War, the Department of Defense and the university research community face a whole new set of challenges. Maintaining support for this historic partnership will be critical to maintain our economic strength and national security.

The MEDEA project, originally called the Environmental Task Force, is one example of the value of continuing this partnership. The fifty scientists involved in the project were cleared to access highly classified information and were provided with detailed information on a number of intelligence and defense databases, technologies, and methodologies which might be used to develop a more complete view of Earth's environment from climate through land use to volcanoes and earthquakes. MEDEA embodies the elements of partnership that should be transferred to other areas--a shared understanding of our common objectives, a mutual respect for our complementary strengths, and a willingness to explore new territory together. Admiral Boorda, Chief of Naval Operations, and Admiral Gaffney, Commander of the Naval Meteorology and Oceanography Command, have testified to the considerable value of this partnership and I will not belabor the point except to mention that I am a member of MEDEA. I have brought along a revolutionary map of the world ocean derived by scientists at Scripps and NOAA from declassified satellite data as a tangible example of the success of this ongoing partnership.

There are other areas where we are working successfully with the Navy. This past summer, Admiral Boorda convened a CNO Executive Board on Oceanography to examine the role of oceanography for the future of the Navy. The Board consisted of members of the academic community as well as Admirals and Navy civilians. The Executive Board launched several initiatives to reinvigorate oceanography's support of Naval operations, including forming an interagency National Oceanographic Facilities Council to coordinate the use of the nation's oceanography assets. I believe that one of the most important recommendations is the Navy's commitment to:

> "Preserve a robust 'at-sea' research and survey capability, including a Navy survey fleet of no less than eight ships to meet the critical data requirements of the fleet commanders.

FLEET ISSUES

The productivity of oceanographic research, the comparative advantage of our naval defense forces, our understanding of climate, and ability to develop new marine products depends on the ability of scientists to conduct experiments at sea. Research at sea provides an invaluable opportunity to collect data and make real-time observations. Most research cruises also include graduate students, training the future leaders in ocean science. While the oceanographic fleet is as large and modern as it has ever been, many federal agencies are funding fewer at-sea research projects. This threatens the long-term health of the academic oceanographic fleet, as well as, the country's ability to maintain a vibrant research program in the oceans.

Scripps ships are part the University-National Oceanographic Laboratory System (UNOLS) fleet. UNOLS, a valuable tool for efficiently distributing capabilities and scarce resources, is an association of institutions that operate and conduct research on the academic fleet. UNOLS provides open access to all vessels by federal, state, and local research programs. The UNOLS fleet is primarily supported by federal funding (attached please find a summary of UNOLS federal support). NSF provides 75% of the funding for the UNOLS operations; the remainder of the funding comes from the Office of Naval Research (ONR), the National Oceanic and Atmospheric Administration (NOAA), other federal and state agencies, industrial, institutional, foreign, and private support. UNOLS institutions also make significant contributions to the fleet. The University of Washington annually contributes 45 ship days on the Thomas Thompson. Scripps contributes about $1.5 million per year for ship support.

The UNOLS fleet is completing an aggressive program of modernization. Planning and funding of this modernization was undertaken cooperatively by the federal government and academic community. An interagency group developed a coherent plan for fleet modernization and retirement which decreases the number of ships. The configuration and justification for the current fleet were driven by the scientific requirements and predicated upon funding agency projections. The competition for the new AGOR was peer-reviewed and supported by all the relevant federal agencies.

During this period of modernization, the United States Navy funded construction of three Class I vessels and supported extensive modifications of two other vessels. In total, the Navy's capital investment over this period is in excess of $150 million. The National Science Foundation also contributed significantly to improving our sea-going assets by acquiring the research vessel EWING and by supporting extensive mid-life refits for its three intermediate class vessels. Currently (FY95), the NSF Ocean Sciences budget spends about 22 cents of every program dollar on ship support.

The academic fleet is the most modern and capable of any national or international oceanographic fleet and the officers and crew are highly professional. The larger ships are all equipped with multi-beam echo sounding systems, many of these are state-of-the art, and the ships are able to support global, regional, and local operations in all fields of oceanography. Institutionally based ships are infused with the energy and innovative spirit of the scientists of that institution. The continuity of crewing that is fostered at UNOLS institutions brings a breadth of experience, knowledge, and professionalism to UNOLS vessels that cannot be found in commercial operations. This invigorates the scientists and causes a synergistic relationship between the crews and scientific parties. This relationship creates the stimulant for successful science at sea.

During the 1990s, there has been a decreased emphasis on Navy support of seagoing research. Because of this, the Navy's return on its capital investment in the fleet--new discoveries enabled by the research conducted on these ships--is in danger. From FY 93-95, ONR averaged only $4.0 million for operational support of academic oceanographic platforms. In contrast, twenty-five years earlier, in 1968, ONR spent $4.1 million. While modeling and the use of satellite data contribute enormously to our understanding of the oceans, these capabilities must be tied to in-situ observations. I am heartened by the Navy's recent statement confirming the importance of a robust "at-sea" research and survey capability. I am also encouraged by the Navy's projected increased use of the UNOLS fleet this year. I urge you to support this trend.

Future funding from the usual sources, primarily NSF and ONR, is not likely to keep up with the costs of operating this fleet. This budget shortfall could cause serious disruptions in critical research, increase cost of research on ships, and lead to political battles over ship lay-ups. Federal support from agencies other than the NSF for UNOLS vessels has dropped by 20% in recent years. As a partial solution to the coming funding short-fall, a new national oceanographic partnership could be formed to broaden the spectrum of agencies within the federal government that actively support the UNOLS fleet, particularly NOAA, DOE and NASA. Broadening the scope of fleet usage to support the missions of these agencies will ensure the future health of the academic fleet and make efficient use of its recent modernization. Agencies outside of NSF must be encouraged to work with the UNOLS ship scheduling process in planning the use of vessels.

For example, currently, the bulk of NOAA's oceanographic research is conducted on NOAA vessels and, as a result, their support for academic sea-going facilities has been weak (3% of the UNOLS budget). In his testimony before you, Jim Baker stated the willingness of NOAA to work cooperatively with UNOLS. I am encouraged by his statement and urge you to continue to encourage NOAA to use the UNOLS fleet for its unmet research ship needs, optimizing previous federal investment and cutting costs.

Another issue that threatens the academic fleet is the addition of new ships without a corresponding increase in support for operations and maintenance. The impending shortfall of funding to support fleet operations would be exacerbated with the addition of "unplanned" ships. The size of the academic fleet is decreasing. As a result, some institutions will lose ships. It is very important that new ships be acquired only when there is a funded research need. The community must work together to ensure that capital construction, vessel operations, and research programs grow in logical proportion to one another. We also need your help to encourage the use of the peer review system if new ships are added to the fleet. Peer review allocates resources where they are likely to produce the greatest return on public investments and the broadest-based benefits.

The academic research fleet faces many challenges in coming years. The health of oceanography and the growing integration of oceanography into global programs requires that the capabilities be maintained and constantly modernized to meet new research challenges. I encourage you to play a leading role in developing and maintaining effective communications between ship operators, users, and the government on the many relevant issues associated with the academic fleet and future research needs.

A NATIONAL OCEAN PARTNERSHIP

New scientific opportunities coupled with major changes in organizations responsible for ocean monitoring and research demand that there be more effective communications between academia and government on ocean priorities. The best approach to ensure this cooperation is through a carefully constructed partnership that takes advantages of the strengths of each sector. A National Ocean Partnership must be developed and funded to take advantage of modern opportunities so that the future impact of climate change, tectonics, and past and future ocean and riverine dumping can be gauged with greater certainty. I look forward to working with you on the development and implementation of such a partnership.

Thank you for your attention. I would be happy to answer any questions you might have.

FEDERAL OCEAN RESEARCH FUNDS/FLEET OPERATIONS FUNDS

NSF:
Currently (FY95), the NSF Ocean Sciences budget spends about 22 cents of every dollar on ship support. The total Ocean Sciences budget (less the Ocean Drilling Program) is $153 million, and $33.9 million (average of FY 93-95) is used for operational support of oceanographic facilities. It is likely that the present balance between science and facilities will be maintained. Any NSF support for major new facilities will require commensurate science support.

Office of Naval Research and other Navy:
The Navy is projecting their use of UNOLS ships will increase beginning in 1996. Navy funding for academic oceanographic facilities has fluctuated widely over the past five years, ranging from $3.1 million to $6.4 million per year. In 1995, ONR budgeted $103 million for basic (6.1) oceanographic science projects and they have averaged $4.9 million (FY 93-95) for operational support of academic oceanographic platforms.

National Oceanographic and Atmospheric Administration:
The NOAA budget for extramural ocean science programs (NURP, Sea Grant, Cooperative Research Institutes, Coastal Ocean Program, Global Change Programs) in 1995 was $79 million. Over the past 3 years, NOAA support for UNOLS operations has averaged $2.1 million. (The bulk of NOAA's oceanographic research has been conducted on NOAA vessels.)

Environmental Protection Agency:
EPA spent $41 million on ocean research in 1995, and $65,000 of UNOLS ship time. The EPA has operated a small fleet of coastal vessels; however, this fleet is aging and may not be replaced.

Other Agencies:
In 1995, NASA, USGS, MMS, DoE and ARPA spent a combined total of $106 million on ocean science programs. The programs spend, on average, less that $900,000 on the UNOLS fleet. (In the past, the USGS operated two large research vessels. These have both been retired and USGS is planning to use the UNOLS fleet.)

SATELLITE DATA REVEAL NEW VIEW OF OCEAN BOTTOM

Scientists at U.C. San Diego's Scripps Institution of Oceanography (SIO) and the National Oceanic and Atmospheric Administration (NOAA) have used satellite measurements to develop the most detailed picture to date of the global sea floor. The computerized image of the sea floor opens new doors to underwater exploration, including identifying previously unknown volcanoes, studying the tectonic history of the oceans, and searching for untapped petroleum reserves.

David Sandwell, a professor at SIO's Institute of Geophysics and Planetary Physics, and Walter Smith of NOAA created the new map by combining newly declassified measurements from the Navy's Geosat satellite with data collected by a European satellite, ERS-1. Scientists have been attempting to map the Earth's underwater terrain using shipboard sonar since the 1920s; however, they were only able to chart about five percent of the global seafloor from ships. Sandwell estimates it would take approximately 125 years to chart the ocean basins using the latest sonar tools.

Fortunately, such a costly undertaking is no longer necessary because scientists have devised a new way to explore the ocean bottom from space. Although satellite sensors are incapable of imaging the seafloor directly, scientists can use satellites to measure the height of the sea surface to fractions of an inch. The gravitational attraction generated by geological structures such as mountains and valleys on the seafloor cause broad bumps and dips on the sea surface. By analyzing the surface gravity fields such structures create, Sandwell and Smith were able to infer what the topography of the sea floor looks like. This analysis provides us with the first overall view of 70 percent of the Earth's surface in very fine detail.

Sophisticated satellite data on the sea surface have only recently been made available to oceanographers. The Geosat data began to be declassified in response to requests from scientists as part of the activities of the Environmental Task Force (ETF). ETF and its follow-on effort, MEDEA, reviewed the feasibility of declassifying intelligence and defense data and systems for use by scientists to address serious global environmental problems. SIO scientists look forward to continuing to work with the national security community on this effort.

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO

SCRIPPS SCIENTISTS PREDICT NEXT EL NIÑO

The El Niño of 1982-83 was devastating worldwide--torrential rains in California destroyed crops and damaged homes, drought in Australia fueled widespread wildfires, tens of thousands of starved sea birds littered tropical islands, tons of dead fish washed up along the coast of Peru. If a Scripps Institution of Oceanography experimental climate forecast is correct, we could be headed for another El Niño in the winter of 1996-97.

El Niño is a periodic climatic condition that warms the Pacific Ocean surface temperatures along a broad band of the equator and shifts wind patterns that cover a quarter of the globe. Among the greatest climatic events of the century, the 1982-83 El Niño wreaked havoc around the Pacific Rim, causing $13 billion in damage.

Tim Barnett leads a research effort at Scripps that utilizes global environmental data and supercomputer capabilities to develop models for forecasting El Niños. The Scripps model is calling for a moderate to severe El Niño for winter 1996-97. According to Barnett, the Scripps prediction is almost outside the range of past occurrences, so the magnitude of the El Niño is uncertain. "If it turns out to be as massive as the experimental model shows, it will rival the global impacts of 1982-1983," he said. "But at this time it is premature to rely on these rather astounding forecasts, because our models are still really research tools."

Reliable forecasting has developed in just the past few years. The major factor that made the difference was intensified data-gathering in the tropical and central Pacific. During the past decade, more than a dozen countries invested in large-scale research programs aimed at understanding how the ocean and atmosphere interact to produce El Niños.

This worldwide investment should have a major pay-off. The successful prediction of seasonal climate variations six to 12 months in advance could save the U.S. billions of dollars in agriculture, transportation, and energy industries alone. For example, climate fluctuations can change production of the world's major crops by as much as 20% in any year. Furthermore, significant savings to the energy and transportation sectors can be realized with advanced warning of freezing conditions in the Nation's waterways. The advantage to having an El Niño forecast a year in advance is that people and governments can consider alternatives for allocating resources, energy policies, and agricultural planning that would minimize the El Niño's impact.

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO

ACOUSTIC DAYLIGHT--HOW TO "SEE" IN THE DARK

Researchers at Scripps Institution of Oceanography led by Michael Buckingham have developed a new imaging technology that allows them to "see" under water using naturally occurring sounds. Called Acoustic Daylight, the technology uses the sound generated by bubbles in the ocean. When these bubbles come into contact with an object, the noise they produce changes. By analyzing these changes, it is possible to create a visual image of the object and display it on a monitor.

Acoustic Daylight promises to be useful for underwater navigation and salvage, and, because the new technology is not detectable, it may prove useful for defense purposes such as detection of mines and submarines and protecting harbors and moored ships.

For many years, the principal means of probing the ocean using sound has been through the use of active or passive techniques. With an active system, an object is illuminated by a pulse of sound, such as sonar, and its presence inferred from the echo it produces. The passive approach involves listening to the sound that an object itself emits, such as engine noise.

"What we are proposing is a new method of employing sound in the ocean, which is neither active nor passive," Buckingham said. "It relies on the naturally occurring ambient noise field in the ocean as the sole source of acoustic illumination."

Noise in the ocean is created by breaking surface waves that create large numbers of bubbles. The bubbles emit noise, and the sound is dispersed throughout the ocean to great depths. The resulting sound is comparable to sunlight, which spreads evenly to all space available. The presence of an object in the ambient noise field modifies the field by scattering acoustic energy in all directions. This scattered radiation can be focused onto an image plane by an acoustic lens, processed by imaging electronics, and displayed on a computer monitor.

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO

IMPROVED OIL SPILL RISK ASSESSMENT IN THE SANTA BARBARA CHANNEL

When an oil tanker carrying 92,000 barrels of refined oil out of San Francisco Bay caught fire and began leaking oil in 1984, emergency crews towed the vessel offshore to the south west in an attempt to protect the coastline. Unfortunately, the currents reversed unexpectedly and oil washed ashore at Bodega Bay. Research conducted at Scripps Institution of Oceanography seeks to prevent a similar occurrence.

A team of Scripps oceanographers headed by Clinton Winant is studying the currents in the Santa Barbara Channel and Santa Maria Basin to develop information that will improve the management of oil spills off the Southern California coast.

The study, funded by the Minerals Management Service (MMS), provides new insight into how an oil spill would spread under various climatic conditions, thus better arming emergency oil containment and cleanup officials to mitigate effects of a spill. The study is also aiding MMS in assessing environmental risk of offshore drilling.

One of the goals of the project is to develop so-called "synoptic views" of current patterns. Synoptic views are commonly used by meteorologists to identify characteristic conditions that trigger certain weather patterns. While the forecasting tool is widely used by meteorologists, the Scripps project represents the first time the approach will be applied to predicting ocean current patterns.

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO

BOTH SIDES OF CLOUDS

Until recently, given their ephemeral existence, clouds were regarded more as passive indicators of short-term weather rather than driving forces of long-term climate. Only now are researchers beginning to appreciate the degree to which clouds determine how much sunlight the Earth accepts or rejects and how much heat it yields back to space. That is what motivates researchers at the Scripps Institution of Oceanography's C4: Center for Clouds, Chemistry, and Climate. C4 is a multi-institutional, National Science Foundation Science and Technology Center, that studies clouds with satellites, sensors, and spy planes, trying to understand the role that clouds play in controlling climate.

Although at any moment they can cover as much as three-quarters of the Earth, clouds remain a mysterious factor in projecting climate. They both heat and cool the planet, and it is unknown which side of their nature will prevail as the climate changes. New research by C4 scientists found that clouds in the tropics trap about 15 to 20 times more solar energy than previously believed. This is significant because the tropics are a major determinant of global climate and atmospheric and ocean circulation. This finding may require major revisions of models used to predict global climate change.

C4 scientists are also researching air pollution in California and major metropolitan areas around the globe, such as Mexico City and Beijing. They are studying the role that sulfur compounds and certain other polluting chemicals may play in the formation of clouds. They are also trying to understand the affects of global warming on regional weather and climate in California and the Midwest. If global warming occurs, these areas are projected to experience reduced rainfall and warmer temperatures, shifting agricultural zones northward.

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO

WEATHER PREDICTION TO IMPROVE NATIONAL SECURITY

Recently, researchers from Scripps Institution of Oceanography participated in an experiment sponsored by the Office of Naval Research to better understand the interaction between oceans, air, and land, and the weather that results from their combination. The ultimate goal, as far as the Navy was concerned, was to improve fleet operations. Understanding the coastal environment is critical to both national security and civilian communities. More than half of the U.S. population lives on the coast and a third of our Gross National Product is linked to the coastal zone. As the population in coastal states increases so does the need to improve the forecasting of local weather and ocean conditions. A better understanding of coastal meteorology would be of considerable benefit to the nation. Coastal meteorology affects air pollution and disaster preparedness; ocean pollution and safeguarding near-shore ecosystems; off-shore oil exploration and drilling; military and merchant ship operations; and a host of other activities affecting commerce, industry, transportation, health, safety, recreation, and national defense.

Coastal meteorology is generally ignored by most meteorologists because it is made difficult and complex by the unique weather and climate conditions created by the diverse properties of land and ocean. The recent ONR/SIO project is changing this fact. SIO researchers expanded the ONR project by installing a network of automated meteorological stations along the Big Sur coast. At each site, a 30-foot tower, with instruments that measure wind speed and direction, air temperature, humidity, and pressure, has been built. Data is collected every minute, recorded onto computers, and analyzed. For the first time, little-understood weather events are being measured and correlated.

SIO researchers are establishing a marine coastal observatory to provide a network of long term measurements to improve our ability to forecast changes in the coastal ocean and atmosphere. The observatory will be part of a sophisticated coastal monitoring system and a "test-bed" platform for new technologies for global change research. The observatory will allow the long time series measurements which are needed to determine changes in the coastal ocean and to ameliorate the potential degradation of the environment due to natural or anthropogenic effects. Comprehensive, real-time information on the coastal ocean and atmosphere, from these platforms and from other sites, will be integrated and made available to researchers, planners, local regulatory authorities, and the general public.

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO

PHARMA-SEA

Researchers at Scripps Institution of Oceanography are leading the way in the discovery of new pharmaceuticals from the sea. Therapeutic drugs have been isolated from a number of marine invertebrates and bacteria, and several products are in various stages of the patent process. For example, the study of squids has shown how the human nervous system works and resulted in new drugs for epilepsy. One of the SIO researchers, Bill Fenical, states: "The land search for new antibiotics has reached a point of diminishing returns." Terrestrial sources alone can no longer provide the needed discoveries. One reason why sea creatures are good sources of anti-disease compounds is that they have elaborate chemical arsenals to protect themselves from predators.

Researchers at Scripps are participating in a cooperative program to develop new anti-cancer agents from marine resources. A recently isolated marine plant with a remarkable diversity of physiological and biochemical features is being screened for biotechnological uses. It can grow in almost saturated brine and produces beta-carotene, which may be a potential anti-cancer agent. SIO scientists also discovered that antarctic plants synthesize protective compounds that absorb ultraviolet radiation (UV). This may have implications for preventing cancers associated with UV increases from the depletion of the Earth's ozone layer.

SIO scientists have identified a new compound that can inhibit the replication of HIV, a virus which is thought to cause AIDS. The compound is produced by a previously unknown species of deep sea bacteria taken from a sediment core from a depth of more than 1,000 feet off the coast of northern California. Another SIO scientist has discovered a chemical from a marine sponge that shows promise for treating inflammation and pain without the problems associated with aspirin and other anti-inflammatory drugs.

Marine physiological research is also developing new biological and medical knowledge: work with shark hearts provides a model of pericardial-cardiac interactions and the filling mechanisms of the human ventricle; studies of swimming fish shed light on the muscle fiber interactions of the systolic heart; research in performance energetics and diving of marine mammals and birds has greatly expanded the knowledge of human aerobic scope and the physiological consequences of pulmonary disease; and investigations of the acid-base balance of ectotherms has revolutionized approaches to hypothermic surgery and to the maintenance of organs for transplant.

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO

A NEW OCEANOGRAPHIC PARTNERSHIP

Led by Walter Munk, researchers at the Scripps Institution of Oceanography propose a new oceanographic partnership--the Joint Ocean Climate Initiative (JOCI).

The ocean plays a profound role in seasonal, interannual and decadal climate changes. JOCI proposes joint use of acoustic (subsurface) and complementary satellite altimeter (surface) measurements. The combination of the tomographic, altimetric and other data obtained from national and international weather services will permit, for the first time, an estimate of the oceanic state virtually from week-to-week. Only with such estimates will it be possible to continue rigorous testing of models, to calculate the way in which the ocean interacts with the atmosphere, and ultimately to forecast future climate.

ONR--The focus on underwater acoustics is critical to improving the U.S. submarine detection capability. Acoustic coherence limits, imposed by natural ocean variability, ultimately determine our ability to use sound for underwater communication, navigation and submarine detection.

NOAA--JOCI would be an element of the global-scale observation system and a forecasting effort using observations based upon modern modeling codes.

NSF--JOCI will focus on the underlying scientific issues and problems of gyre dynamics. This is one of the least understood aspects of ocean dynamics owing to the historical difficulties in obtaining adequate observations of the time variability.

NASA--Satellite altimetry has emerged in the last three years as the central element of a true global ocean observing system. JOCI will exploit the NASA capability and complement it with measurements and scientific activities required to produce a serious system directed at understanding the ocean and climate.

SERDP--Accurate information on hearing capabilities of marine mammals and sea turtles, and on the response of marine mammals and other marine organisms to man-made sounds, is badly needed to support formulation of rational policies for the use of sound in the sea.

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO

Written Presentation to Joint Briefing of House Science Committees

Dr. Gary B. Griggs
Director-Institute of Marine Sciences
University of California, Santa Cruz

Subject: Leveraging National Oceanographic Capabilities

Like Jim Kennett, I left an undergraduate Oceanography class this morning, with nearly 200 students; a class I have been teaching for 27 years. I have now have had over 6000 students in this course and a similar number have taken a companion course taught by colleagues; this totals about 12,000 interested students over this time period. Oceanography continues to be one of our most popular introductory science courses and are students remain interested and curious about this large and somewhat unknown portion of our planet. This class gives me the opportunity to impress upon these young people the significance of the oceans to our past, present and future.

The Oceans are truly immense, and

- cover 71% of earth's surface
- include 300 million cubic miles of water, 97% of the total on earth
- the include the great majority of the earth's habitat, because of their great volume, (ocean has an average depth of 2.5 miles),
- if we leveled the earth's surface, we wouldn't have any land, but the entire globe would be under 1.5 miles of seawater- we are indeed an ocean planet

Since I began teaching this class in 1969, the population of California has increased 60% from 20 to 32 million, and most of these new people want to live on the coast. Unfortunately 86% of California's shoreline is eroding which presents some significant problems to the state. If all of us went to the California coast at the same time, we would each have about 2 inches. Unfortunately only about 25% of the shoreline is accessible such that we only have about a half an inch apiece, and even this has to be shared with visitors from other states and countries. No wonder it feels crowded. It is.

Meanwhile, in this same 27 year period, global population has increased 50% from 4 to 6 billion, and they all, at a minimum, need someplace to live, something to eat, and some energy. Many would like to believe that the oceans can somehow provide for all of their needs, but this is probably wishful thinking.

Although the oceans cover 71% of the earth's surface, they provide only about 16% of humanity's food supplies. Overfishing has had a significant effect on global fish populations. Fish catches are declining in 13 of the world's oceans' 15 major fishing areas, and most scientists would agree that the 90 million tons taken globally in 1995 is the peak and declining catches will be the case in the future. I don't believe that there is any immediate solution to this declining "renewable" resource dilemma.

The oceans at present also provide about 25% of our oil and gas, very obvious here in the Santa Barbara area. This is one of the few areas where private industry has made a major investment in marine research. We need to ask why has this been the case? Why hasn't there been more industry investment and involvement in ocean research? I think for the most part this is because most of the private industry involved with the ocean is relatively small operations and simply are heavily into research.

In 1969 we were still theorizing about the history of the earth and the ocean. We were just beginning the Deep Sea Drilling Project (now Ocean Drilling Program-ODP) which has been one of the most successful long-term scientific research efforts in the history of man, a joint federal agency/university and US/international effort which has led to our present understanding of the origin and development of the earth and oceans, ocean circulation and climate change, the distribution of earthquakes and volcanoes, and a myriad of other important scientific discoveries. Congress can take great pride in maintaining this program for over 25 years which has been an important element in establishing and maintaining US scientific leadership in oceanography.

At about that time, we also had the Santa Barbara oil spill, a wake up call to the potential impacts of human activity on the oceans and our coastlines, the ~ 3,000,000 gallons spilled was less than a third spilled by the Exxon Valdez nearly 20 years later in Alaska.

Most of the world's populations, including that of the US lives on or near the coastline; this is where many of the world's largest cities were built, primarily because of access to the sea for transportation. At present 80% of all the world's commerce is moved by sea. But that adjacent coastal ocean has also provided a convenient place to dispose of our wastes, which have grown in volume, and toxicity.

The impacts of these coastal concentrations of people and the natural hazards which threaten or impact these coastal environments have led to a partial redirection of our oceanographic research to the coastal zone, but this will have to continue to an even greater degree if we are going to continue to live in any reasonable way in this active physical environment. The impacts of hurricanes on the increasing populated Atlantic and Gulf Coast Barrier Islands; the potential impacts of large offshore earthquakes and their associated tsunamis on the coastal areas of the Pacific Northwest, Alaska, and Hawaii; the impacts of coastal storms on the densely populated beachfront and cliffside dwellings in California; the loss of wetlands and threats to commercially important fish and shellfish; the problems associated with maintaining adequate depths in our harbors due to the increasing concerns and requirements regarding disposal of contaminated dredge spoils; dealing with beach and shoreline losses and their impacts on tourism; water quality concerns from the myriad of waste disposed of in the coastal zone, are some of these area of concern for the coastal oceans. These affect us daily and will continue to do so. We need to understand these threats and impacts so we can make the right decisions for the future now. We cannot stop hurricanes so we better figure out how to reduce our future losses rather than allow more people to move to low-lying hurricane prone areas.

The importance of the oceans to our future, the resource challenges and potential economic opportunities the ocean provides, the quality of life and national security issues have been discussed and itemized by national leaders at the January 25 hearing.

The questions before us now, and I mean us, are how do we collectively refocus our ocean research agenda to meets these obvious needs, frame and then answer the questions we agree are the most important ones, work more efficiently, utilize existing and new data more effectively, develop new techniques and instrumentation to better monitor, measure and understand this complex ocean world, and share our nation's collective facilities and expertise from government, academia, and private industry to make the whole greater than the sum of its parts. How do we maintain our global leadership in the understanding, utilization and protection of the oceans?

TABLE 1. MAJOR MARINE SCIENCES FACILITIES IN THE MONTEREY BAY REGION

1. Institute of Marine Sciences-Long Marine Laboratory (University of California, Santa Cruz)
    Focus: Marine mammals, aquatic toxicology, continental margin tectonics, coastal hazards, ocean processes and paleoceanography
    Researchers/graduate students/staff: 186
    Annual budget: $7.5 million

2. United States Geological Survey-Branch of Pacific Marine Geology (relocating)
    Focus: Marine and coastal geological investigations of the continental margins of the western U.S., Alaska, Hawaii and trust territories
    Researchers/staff: 120
    Annual budget: $14 million

3. California Dept. of Fish and Game-Oiled Wildlife Rescue and Rehabilitation Facility
    Focus: Rescue and rehabilitation of oiled wildlife and aquatic toxicology research
    Researchers/staff: 5
    Annual budget: $500,000

4. Moss Landing Marine Laboratories (California State University)
    Focus: Physical, chemical, and biological oceanography, marine ecology
    Researchers/graduate students/staff: 140
    Annual budget: $6.2 million

5. Elkhorn Slough National Estuarine Reserve and Elkhorn Slough Foundation
    Focus: Ecology, biology, estuarine management and restoration
    Researchers/staff: 12
    Budget: $600,000

6. Hopkins Marine Station (Stanford University)
    Focus: Marine invertebrate biology and ecology
    Researchers/graduate students/staff: 58
    Budget: $3.2 million

7. Monterey Bay Aquarium
    Focus: Public education and marine research relevant to exhibit program
    Researchers/staff: 350
    Budget: $25.8 million

8. Monterey Bay Aquarium Research Institute
    Focus: Technology-enabled ocean science; deep sea geology and geochemistry, biology and microbiology; upper ocean physics and biogeochemistry. Instrument and sensor development for fundamental ocean research. Underwater vehicle technologies
    Researchers/staff: 91
    Budget: $11.4 million

9. Naval Postgraduate School
    Focus: Physical and chemical oceanography and meteorology
    Researchers/graduate students/staff: 136
    Budget: $4 million

10. Ocean Applications Branch (NOAA)

Focus: Development, exchange, integration, and dissemination of oceanographic data, services, and products in support of NOAA marine programs
Researchers: 10
Budget: $800,000

11. Pacific Fisheries Environmental Group (NMFS/NOAA)
    Focus: Assessment of effects of natural environmental variability on living marine resources
    Researchers: 15
    Budget: $800,000

12. Naval Research Laboratory, Marine Meteorology Division
    Focus: Atmospheric research and forecasting
    Researchers/staff: 59
    Budget: $8 million

13. Fleet Numerical Meteorology and Oceanography Center (FNMOC)
    Focus: Provides oceanographic/atmospheric service to DOD
    Researchers/staff: 300
    Budget: $22 million

14. National Weather Service Forecast Office (NOAA)
    Focus: Provides marine and terrestrial weather information and forecasting
    Staff: 45
    Budget: $2.5 million

15. Monterey Bay National Marine Sanctuary Office (NOAA)
    Focus: Protection and management of Monterey Bay National Marine Sanctuary
    Staff: 5
    Budget: $600,000

16. Monterey Marine Resources Laboratory (Calif. Dept. of Fish and Game)
    Focus: Research and management of living marine resources
    Staff: 25
    Budget: $1.25 million

17. Marine Pollution Studies Laboratory (Calif. Dept. of Fish and Game)
    Focus: Research on effects of marine pollution on living marine resources
    Staff: 32
    Budget: $2.6 million

18. National Marine Fisheries Service Laboratory (NMFS/NOAA)
    Focus: Pacific Coast groundfisheries research
    Staff: 28
    Budget: $1.6 million

TOTALS
Researchers/staff/graduate students: 1,617
Budget: $113.35 million

I understand that a central purpose of these regional briefings is to hear from some different ocean communities as to their perspectives and gather input to help Congress develop their ocean agenda. I want to offer that perspective from the Monterey Bay ocean sciences community.

Monterey Bay is emerging as a national center for marine research and education because of 1) the physical uniqueness, biological diversity and relatively pristine nature of the offshore ocean; water 5,000 feet deep lies within a few miles and a few minutes of the shoreline and is incredibly rich biologically, 2) the long history of oceanographic research and reputation of the research facilities in the area, 3) the community and political support for this kind of activity, and now 4) the nation's largest National Marine Sanctuary.

There are now 18 oceanographic institutions or governmental ocean agency facilities around the margins of the bay or planning on relocating here. These include about 1500 scientists and staff and a total operating budget in excess of $100 million (see attached article from SeaTechnology, May 1995 and map and summary).

These include 3 public and private University marine institutes, several state agency facilities; Monterey Bay Aquarium, one of the nation's finest aquariums; Monterey Bay Aquarium Research Institute (MBARI), perhaps the worlds' premier research facility for developing technology and instrumentation for sampling, sensing, probing and monitoring the ocean, all possible because of the insight, leadership and vision of David Packard who endowed MBARI. There are also a number of federal ocean facilities: four NOAA facilities and one preparing to relocate (National Weather Service Office, Sanctuary Office, Ocean Applications Branch, Pacific Fisheries Environmental Group as well as a major fisheries lab planning on relocating to the bay), and the Naval Postgraduate School (NPGS), Naval Research Laboratory, and the Fleet Numerical Meteorology and Oceanography Center. Each of these groups is distinct in their mission and research capabilities, and there is surprisingly little overlap or duplication.

Former Congressman Leon Panetta saw the strength in this diverse collection of marine facilities and worked to bring them together; Congressman Sam Farr has continued this effort and also worked to attract new facilities to this emerging center, now framed by the Monterey Bay National Marine Sanctuary. As a result, rather than competing for research dollars and staking individual claims in the offshore areas, the directors communicate regularly, and interaction, collaboration and shared resources is becoming the rule. A few examples from my own institution(UCSC-University of California, Santa Cruz):

- ONR recently funded a 5 year $4.5 million collaborative project between NPGS, NOAA, the MBARI and UCSC to collect and process ocean and meteorological data and then develop the programs to visually display offshore weather conditions as they develop. Each facility and their scientists and engineers bring unique strengths to this project which couldn't have been done without all of their individual efforts.

- UCSC has just signed a memorandum of understanding with NPGS to allow exchange of students, collaboration in research and public service/information supply.

- UCSC has scientists with joint appointments at MBARI so their scientists can sponsor graduate students from UCSC and offer courses. In turn, our faculty can use their ship, submersible and other facilities, and they have helped to fund a sophisticated isotope geochemistry lab on our campus, which they can utilize without having to duplicate and maintain their own facility.

- The Packard Foundation recently funded a $1,000,000 ocean sciences and engineering endowment to provide seed funds for UCSC researchers to initiate new projects with other institutions around the bay, such as MBARI.

- We have a cooperative agreement with a small National Biological Service field unit which is located on campus and is focused on marine mammals, primarily sea otters on the west coast. They work collaboratively with our faculty and students for cost savings and mutual benefit. In exchange for office and lab space, they teach occasional courses and support student research.

- UCSC has developed a cooperative program with the USGS which involves our operating and sharing their research vessel, collaboration and support of graduate student research, and a plan under review to move a group of USGS coastal scientists to our marine laboratory, on the Sanctuary's rim.

- We have been working for nearly 5 years to relocate a key groundfish and salmon fisheries group from NMFS to our marine lab, although this has been a very complex and difficult undertaking in these times.

There are important mutual benefits for federal agencies such as NBS, NMFS, USGS and the University of California in having collocated facilities and cooperative agreements, including:

- shared laboratory facilities, ships and libraries which means significant cost savings in not needing to duplicate facilities
- a cadre of bright and motivated graduate and undergraduate students available for research projects for these agencies
- opportunities for collaborative and symbiotic research.

I believe that this is an important direction we need to move towards, to get the federal research programs out of the large national centers and into proximity and working in partnerships with university research groups. Woods Hole and Scripps provide some good examples of such a successful collocation.

This is consistent with the mission of CORE and consistent with the comments made by Dr. Bruce Alberts of the National Academy before you several weeks ago:

- Federal and academic researchers should improve the cooperative use of facilities and the conduct of joint research.
- Each agency with an ocean mission should establish permanent mechanisms for ensuring outside scientific advice, review and interaction.
- The excellent relationships of NSF and ONR with the academic community must be maintained and strengthened.
- We need stronger partnerships between academic scientists and NOAA, NASA, DOE, USGS, and MMS. This would ensure us of diversity and vitality in the national oceanographic effort.

There are some very real advantages to the nation of extramural research and agency partnerships with universities which CORE has articulated in a recently Public Policy Position Paper:

1. Because University research funds are awarded through peer-review, competition ensures that the best science is supported by tax dollars and research duplication is

minimized. Only rarely is in-house federal research subjected to the discipline of such competition.

Representative Weldon raised this issue with Dr. Alberts in the earlier hearing, and asked if earmarking programs should be replaced with competitive peer review? Dr. Alberts responded that if we want the best value for the money, we have to open up everything we can to competition. Its something nobody denies, its just hard to get it done. I firmly believe that we need to make that effort in order to improve both the quality of our nation's ocean sciences and its research efficiency and effectiveness.

2. From the CORE position paper: The costs of University research or facilities to the federal government are borne only for the duration of the grant or contract supporting the research. When the program is concluded, the agency can move on to a new project without having to carry continuing costs of the federal staff that would have been hired.

3. As an alternative, university research provides the option for rapid changes, lending flexibility rather than inertia to changing priorities.

4. Sponsored research in universities supports the training of the next generation of scientists and engineers. Because peer-review ensures that funds are awarded to the best scientists, the graduate students supported receive the best training available.

5. Federal agency programs are typically driven by a centralized Washington perspective, one necessarily more narrow than regional needs would dictate. Coastal environmental issues, for example, have a strong regional cast that can best be met by local universities.

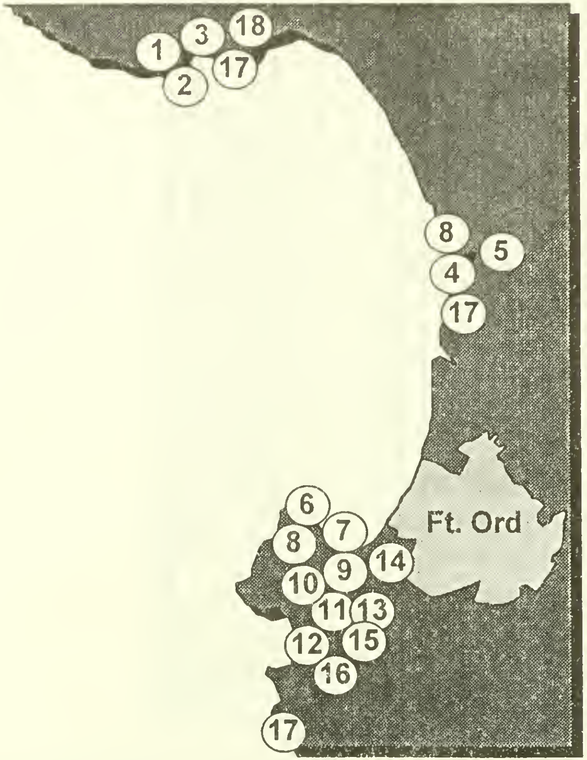
6. For all of these reasons, rescissions or budget reductions that fall most heavily on extramural research are counter to the needs of the nation for innovation and scientific leadership and to the logic that demands reduction of the Federal bureaucracy.

Incentives need to be developed which move us nationally in the direction of government agency/university partnerships such as those we are developing around Monterey Bay, and in increased extramural research support by federal agencies.

Several participants in the January 25 hearing raised the issue of the communication of scientific findings to congress and the public. Congressman Kennedy asked "why can't the scientists come up with a way of hitting us between the eyes on the significance of the oceans and survival of the planet?" I completely agree with the need, and I think the simple answer is that most scientists, unfortunately, aren't comfortable with the public or political arenas and haven't historically seen this effort as part of their responsibility. There are others like Bob Ballard who are quite comfortable and see this as part of their responsibility and mission.

We need to find avenues, such as this process, whereby the most up to date and most accurate information from the best scientists is requested and can be put into the decision making process, whether it be on global warming, limitations on fish catches, or the state of marine pollution by chlorinated hydrocarbons. We all need to know what is working and what isn't and what examples and models exist for getting the best ocean science possible out of our research dollars, how to use our institutional resources more cooperatively, and most importantly, we need to recognize the significance of the oceans to our past, present and future and work to restore federal support to marine research to its level of 15 years ago.

Monterey Bay Marine Science Facilities



1) Institute of Marine Sciences (UCSC)
2) Branch of Pacific Marine Geology (USGS)
3) Oiled Wildlife Rescue/Rehabilitation Facility (CDFG)
4) Moss Landing Marine Laboratories (CSU)
5) Elkhorn Slough National Estuarine Reserve/Elkhorn Slough Foundation
6) Hopkins Marine Station (Stanford University)
7) Monterey Bay Aquarium
8) Monterey Bay Aquarium Research Institute
9) Naval Postgraduate School
10) Ocean Applications Branch (NOAA)
11) Pacific Fisheries Environmental Group (NOAA)
12) Naval Research Laboratory, Marine Meteorology Division
13) Fleet Numerical Meteorology and Oceanography Center
14) National Weather Service (NOAA)
15) Monterey Bay National Marine Sanctuary Office (NOAA)
16) Monterey Marine Resources Laboratory (CDFG)
17) Marine Pollution Studies Laboratory (CDFG)
18) National Marine Fisheries Service Laboratory (NOAA)

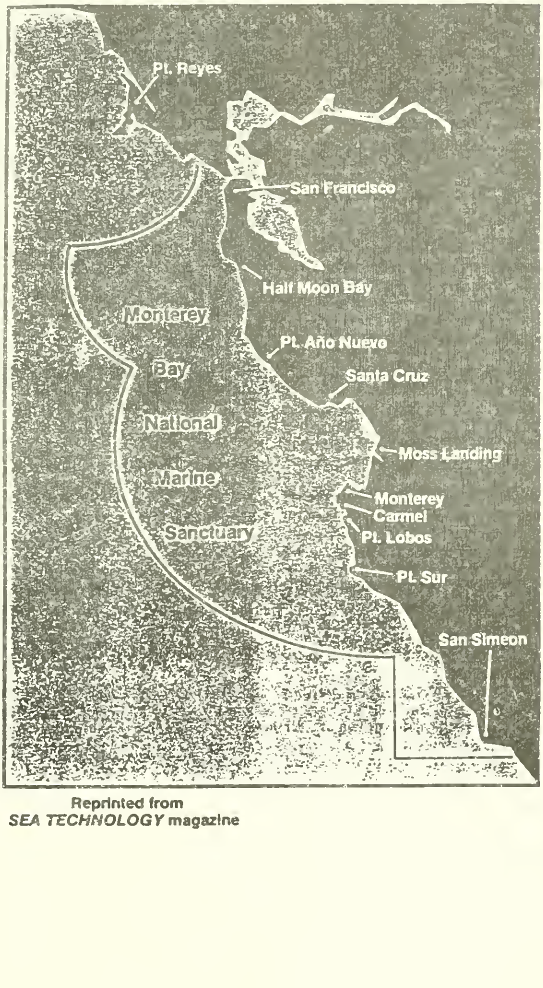
Monterey Bay, National Center for Marine Science

Uniqueness of the Bay Area Attracts 18 Marine Science Agencies/Programs with Budgets Totaling $110 Million

By Dr. Gary B. Griggs
Director
Institute of Marine Sciences
University of California/Santa Cruz

One hundred years ago, Stanford University's Hopkins Marine Station set up shop next to what was to become "Cannery Row." John Steinbeck's classic story partially memorialized the attraction between one of the first marine biologists on the bay with the productive and diverse intertidal zone of the Monterey Peninsula.

Over the last several decades, the marine biologists at Hopkins were joined by the oceanographers at the Naval Postgraduate School in Monterey and the marine scientists and students at Moss Landing Marine Laboratories and the University of California/Santa Cruz. The biological and geological diversity of the bay and the reputations of the marine



Monterey Bay marine science facilities include: (at Santa Cruz) Institute of Marine Sciences, Branch of Pacific Marine Geology (USGS), Oiled Wildlife Rescue/Rehabilitation Facility, Marine Pollution Studies Laboratory, and the NMFS Laboratory; (at Moss Landing) Moss Landing Marine Laboratories, Elkhorn Slough National Estuarine Reserve, and Marine Pollution Studies Laboratory (also at Santa Cruz and Monterey); (at Monterey) Hopkins Marine Station, Monterey Bay Aquarium, MBARI, Naval Postgraduate School, NOAA's Oceans Application Branch, Pacific Fisheries Environmental Group; NRL's Marine Metrology Division, FNMOC, NOAA's HWS, NOAA's National Marine Sanctuary Office, Marine Pollution Resources Laboratory, and Marine Pollution Studies Laboratory lso at Santa Cruz and Moss Landing).

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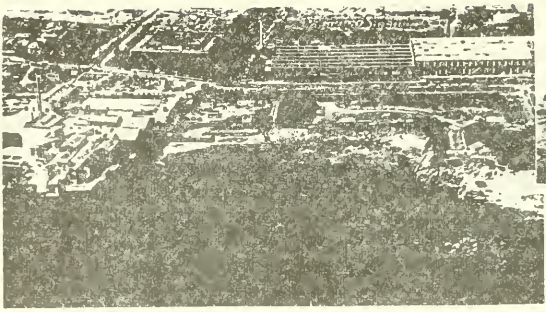
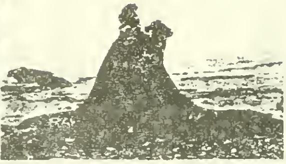




institutions surrounding this remarkable stretch of coastline continue to draw new scientists and programs.

The scientific involvement with Monterey Bay changed dramatically in the early 1980s when computer pioneer David Packard set out to fulfill a dream. In 1984 the Monterey Bay Aquarium opened and for the first time residents of the bay communities as well as visitors from around the world could see first hand what made the bay so exciting to marine scientists. School children numbering 600,000 and 18 million total visitors have had the opportunity to get a glimpse of the diversity of life beneath the waves.

Packard's vision did not end with the aquarium; with an extremely successful public education program in place, he returned to his lifelong interests in technology and invention and started planning the Monterey Bay Aquarium Research Institute (MBARI). Established in 1987, MBARI has taken Packard's successes in the electronics and engineering fields, modified them for salt water, and put them into the bay.

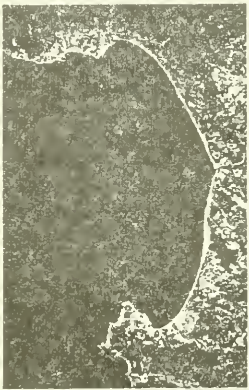
'Impressive Group' of Researchers

With the new leadership of Director Peter Brewer and an endowed multimillion dollar budget, MBARI has attracted an impressive group of scientists and engineers who are applying space-age technology to marine sciences. The development of ROVs with state-of-the-art video cameras has enabled not only MBARI scientists but also colleagues from neighboring institutions and aquarium visitors to observe the diverse inhabitants of the bay and canyon in their natural environment.

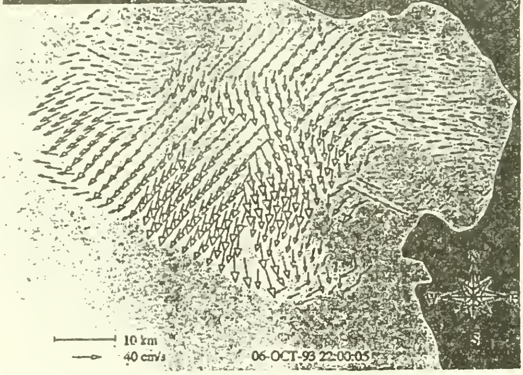
This is in contrast to the typical disturbed and damaged state of most organisms retrieved from deep-water sampling nets and trawls.

MBARI has become one of the world's leading centers for developing instrumentation and technology to probe, sample, and study the ocean waters and the seafloor. MBARI and U.S. Geological Survey scientists working on a joint project have recently discovered deep, fresh-water cold seeps on the floor of the bay that are surrounded by colonies of organisms supported by chemosynthesis in contrast to the photosynthesis-based life which characterizes the rest of the ocean.

Congressman Sam Farr (D-California), a lifelong resident of the Monterey Peninsula, and former Con-



In upper left photo, a portion of Hopkins Marine Station, the oldest marine laboratory on the West Coast, is on the right and one of the newest—the Monterey Bay Aquarium—is on the left. At top right, two male northern elephant seals at Año Nuevo Island, just north of Monterey Bay, fight for control of a harem of females. Below, surface current patterns in Monterey Bay are delineated by a cross-bay radar system. The composite high altitude photographic image of Monterey Bay (left) shows the extent and configuration of Monterey submarine canyon.



House chief-of-staff), have also shared a vision of Monterey Bay and the central coast. Farr saw the potential for the bay to become a center for marine sciences years ago and has worked relentlessly to bring together those involved with the bay to focus their energies and deal with regional issues and problems. He initiated regular meetings of the directors of the marine institutions surrounding the bay to encourage collaborative research and cooperative programs that would create a whole bigger than the sum of its parts.

And it's working.

Converting Floods of Data

Two years ago, the Office of Naval Research funded a five-year $4.5 million joint research project between computer engineers at UC/Santa Cruz and scientists at MBARI, the Naval Postgraduate School, and National Oceanic & Atmospheric Administration (NOAA). The focus of the grant is to convert the flood of data obtained from ships, satellites, and monitoring instruments on winds, waves, temperatures, and ocean currents to pictures of marine and weather phenomena in the Monterey Bay area using computer graphics. Through this effort in computer visualization, these scientists and engineers hope to better understand how the ocean and atmosphere along the central coast interact to produce our varied weather conditions.

There are now 18 marine laboratories or agency facilities either located on the margins of Monterey Bay or in the process of relocating here. These programs, employing more than 1,600 scientists, graduate students, and support staff, have an annual budget in excess of $110 million. Some of these, like the Monterey Bay Aquarium and Long Marine Laboratory of UC/Santa Cruz are well known and visited by the public daily. Others, such as the Naval Research Laboratory (NRL) or the Fleet Numerical Meteorology & Oceanography Center (FNMOC) are important national facilities involved in global research and monitoring programs but not well known by the general public. Collectively, these laboratories and research centers constitute perhaps the highest concentration of marine scientists per mile of shoreline of any place in the world. Additional research groups have expressed interest in relocating here.

Monterey Bay's characteristics stem proximity to major features of oceanic circulation and the dramatic contours of its seafloor, including one of the world's largest submarine canyons. Straddling subtropical and temperate climatic zones, Monterey Bay experiences great variation arising from changes in winds and adjacent ocean currents.

From February to September, northwest winds combined with the Coriolis effect push coastal surface waters offshore and nutrient-laden deep water flows to the surface on an episodic basis. After winds die down in the fall, upwelling decreases and biological productivity declines. In winter, the north-flowing Davidson Current provides a partial warming influence and significant upwelling doesn't begin anew until February when the winds shift again.

The intense biological productivity from seasonal upwelling is combined with the intersection of subtropical and temperate conditions to produce an ecosystem that is more complex than either condition alone. This combination of factors produces one of the richest marine faunas and floras in the world.

The West Coast of North America is famous for its diverse marine flora, and 80 percent of the seaweed occurring between Puget Sound and Southern California can be found in the vicinity of Monterey Bay. The diverse habitats include the mudflats of Elkhorn Slough, the kelp forests of the Monterey Peninsula, the depths of Monterey Canyon with its cold seeps, the invertebrate-rich intertidal reefs at both ends of the bay, and the clean sand bay beaches. These habitats support countless invertebrates, a diverse group of marine mammals (26 species—the greatest species diversity of marine mammals of any area in the northern hemisphere), and 94 species of seabirds.

As the research and education value of Monterey Bay and the surrounding waters have become more apparent, the threats and impacts of human activity have also been recognized.

In October 1992, recognition of this unique stretch of coastline was achieved when the Monterey Bay National Marine Sanctuary was dedicated. The nation's largest and the world's second largest sanctuary encompasses 5,300 square miles of coastal water and seafloor. This designation provides permanent protection for one-fourth of the entire California coast and also preserves the natural resources for generations to come.

The marine laboratories and state and federal agency programs located on the bay margins or planning to relocate here focus their research on a wide range of research topics important both to the residents of the communities around Monterey Bay and to the nation and world. A summary of these programs was prepared in June 1992 by NOAA's Office of Strategic Planning (*The Monterey Bay Connection: A Prospectus for Scientific Excellence in the 1990s*) in response to a request by Dr. John Knauss, then undersecretary of commerce for oceans & atmosphere, and forms the basis for the following summary.

Marine Science Agencies, Programs

The Institute of Marine Sciences, UC/Santa Cruz, an organized research unit within the university with 25 affiliated faculty members from five academic departments as well as 20 to 25 researchers, focuses on marine mammals, aquatic toxicology, continental margin tectonics, coastal hazards, ocean processes, and paleoceanography. Total staff including graduate students numbers 186. The annual budget is about $7.5 million. Besides a new, on-campus Earth and Marine Sciences building, it operates the Long Marine Laboratory on the northern edge of Monterey Bay. Long Marine Lab supports research in marine vertebrate biology, environmental toxicology, and near-shore ecology/invertebrate marine biology / molecular marine biology plus a public education program. On-campus efforts include marine geology and geophysics, ocean processes and paleoceanography, and coastal processes and hazards research.

The Branch of Pacific Marine Geology (BPMG) (to be co-located at the Long Marine Laboratory by mid-1997) is the branch of the U.S. Geological Survey that conducts marine geological, geophysical, and geochemical studies of seafloor regions in the Pacific and Arctic basins and their margins (western United States, Alaska, Hawaii, and the Trust Territories) under the auspices of the Marine and Coastal Geology Program. The program is focused on environmental quality and preservation, geologic hazards, seafloor resources, and public information. The USGS marine program is currently expanding its capability to provide timely and relevant information to collaborators, policy makers, and the general public through increased emphasis on information dispersal. It has a staff 140 and an annual budget of about $14 million.

The emphasis of research program efforts will be on the components that will benefit most from the enhanced collaboration opportunities with researchers at UC/Santa Cruz and elsewhere in the Monterey Bay area. Major research topics are expected to include the Monterey Bay National Marine Sanctuary and adjoining regions: neotectonics, deformation, and associated geologic hazards of central California; and coastal and seafloor erosion and sediment and contaminant transport.

Oiled Wildlife Rescue and Rehabilitation Facility, California Department of Fish and Game. In 1991, the Office of Oil Spill Prevention and Response was created within the Department of Fish and Game to respond to and prevent oil spills in California's coastal waters. The program was required to plan and construct a response/rehabilitation facility to rescue and rehabilitate marine mammals and birds (principally the endangered California sea otter) in the event of a large spill on the central coast. This facility has been designed and will be constructed in 1995/1996 at the University of California's Long Marine Laboratory. The facility plans include laboratories and outdoor tanks to provide a comprehensive response system for cleaning and rehabilitating oiled sea otters and marine birds. During non-oil spill periods, the laboratories and mammal pools will be used for joint University of California/state marine toxicology research. It has a staff of five and an annual budget of about $500,000.

Moss Landing Marine Laboratories was established in 1966 as a marine research and educational facility operated by a consortium of six campuses of the California State University System. Course work is offered to qualified upper division undergraduate and graduate students in the marine areas of ecology, ichthyology, birds and mammals, invertebrates, phycology, and physical, chemical, biological, and geological oceanography with extensive field and laboratory experience. Faculty and student research is incorporated within the marine areas of habitat, geology, physical oceanography, biology and chemistry, pollution, and ecology. Researchers, graduate students, and staff number about 140. The annual budget is about $6.2 million.

The **Elkhorn Slough National Estuarine Research Reserve** program provides information and models on how to best manage the nation's estuaries. It focuses on ecology, biology, estuarine management, and restoration. The 1,400-acre Elkhorn Slough National Marine Reserve, the first established in California (1978) is now one of 22 nationwide. The reserve and the non-profit **Elkhorn Slough Foundation** at Moss Landing help to protect and manage one of the few relatively undisturbed coastal wetlands remaining in California. Maintaining strong ties with local scientists, the staff of 12 with a budget of about $600,000 provides research opportunities for students and interns from other institutions.

Hopkins Marine Station, established in 1891, is the oldest marine station on the West Coast and second oldest in the nation. A teaching and research facility, it functions as a branch of the Department of Biological Sciences of Stanford University. The focus of research and teaching is on the biology of marine organisms, specifically the interactions between organisms and their environment, with an increasing emphasis on molecular marine biology. Students may work towards master's or doctorate degrees in a multitude of specializations. The staff including researchers and graduate students number 58. The annual budget is about $3.2 million.

The **Monterey Bay Aquarium** attracts well over a million and a half visitors annually. The mission of its research division is to contribute to the knowledge of the biology and husbandry of Monterey Bay's organisms through a program of basic and applied research especially in regard to organisms relevant to the aquarium's exhibit program. The exhibit program includes biology and social organization of the California sea otter and biology of deep-sea and open ocean organisms. It promotes interactions with neighboring academic and scientific institutions and provides research opportunities for visiting investigators. The aquarium has a staff including researchers of 350 and about a $25.8 million annual budget.

Monterey Bay Aquarium Research Institute focuses on technology enabled ocean science, deep-sea geology and geochemistry, biology and microbiology, upper ocean physics and biogeochemistry, instrument and sensor development, and underwater vehicle technologies. MBARI's ROV Ventana and support ship R/V *Point Lobos* were core elements in leading to exceptional deep-ocean observing and experimental capabilities and important advances in telemetry and systems development. (MBARI transmits live broadcasts from the ROV to the Monterey Bay Aquarium.) Research activities include advances in buoy technology through development of controllers and sensors, undersea robotics, chemical micro-sensor technology for long-term acquisition of chemical signals, and advanced scientific information management.

MBARI has under construction an advanced, ocean-capable SWATH (small waterplane area twin hull) vessel with 24 berths. The ship will support an advanced 4,000-meter-capable ROV. Also laboratory construction in Moss Landing will be complete in 1995.

It established post-doctoral fellowship as well as collaborative research programs in science and engineering.

Principal support of MBARI is from the David and Lucile Packard Foundation. Total staff numbers 91 and the annual budget is about $11.4 million.

The departments of oceanography and meteorology of the **Naval Postgraduate School** (Monterey) provide master's and doctorate degrees for military officers—more than 4,000 postgraduate degrees since the establishment of these programs in 1968 and 1946, respectively. The overall research goal of the Department of Oceanography—improving ocean prediction—is pursued through four subject areas: acoustical oceanography, coastal and near-shore oceanography, ocean modeling, and air/sea interaction. Meteorology research at the school is focused on numerical weather prediction, geophysical fluid dynamics, analysis of atmospheric systems, tropical meteorology, boundary layer meteorology, and remote sensing. There are 136 researchers, graduate students, and staff. The annual budget is about $4 million.

NOAA's Ocean Applications Branch of the National Ocean Service was established at Monterey in 1985 as a national center for the development, exchange, integration, and dissemination of oceanographic products and services in support of NOAA's high priority marine programs. The branch also serves as a center for coordination and collaboration between NOAA and other marine agencies, programs, and institutions. It focuses on ocean data management, ocean modeling, and ocean research. Highest priority has been directed towards the development of a system for providing direct access to marine data by a wide variety of users. The branch has 10 researchers and a budget of $800,000.

NOAA's **Pacific Fisheries Environmental Group (PFEG)**, established in 1969, is the only laboratory in the National Marine Fisheries Service (NMFS) that focuses on comprehensive assessment and understanding of the fundamental effects of natural environmental variability on living marine resources. This group concentrates on understanding how commercial fish populations are affected by natural environmental variations interacting with human activity. The principal research areas include the development of environmental index time series, diagnostic studies of marine environmental anomalies such as El Niño, identification of environmental/biological causal linkages, interregional comparative studies, and development of environmental-dependent fishery modeling methodology. Given the large spatial and temporal scales studied, PFEG collaborates extensively with scientists from several nations. PFEG has 15 researchers and a budget of $800,000.

NRL's **Marine Meteorology Division (MMD)** is a comprehensive atmospheric research organization with primary focus on global to mesoscale weather prediction. The goals of the MMD are to improve the quality of forecasting techniques and the products available, to increase the Navy's knowledge of its operational environment, to develop techniques for assessing the effects of atmospheric conditions on ships and air platforms, and on shipboard, airborne, and land-based naval communications, sensors, and weapon systems. The goal is also to improve techniques for the processing, display, and utilization of environmental satellite data in support of fleet operations. MMD has a research staff of 59 and a budget of $8 million.

Fleet Numerical Meteorology and Oceanography Center is the Navy's primary real-time numerical prediction center processing regional and global-scale oceanographic/atmospheric models and applied products. FNMOC will soon be the Department of Defense's numerical prediction center. Operating 24 hours a day, 365 days a year, FNMOC provides data to the Navy and oceanographic assistance to DoD. Through various intergovernmental agreements, FNMOC also serves other organizations and interests. It maintains one of the world's most complete global, real-time databases of conventional and remotely sensed oceanographic and atmospheric observations. Some key products include:

- Global and regional atmospheric analyses and forecasts of meteorological parameters
- Global and regional ocean analyses and predictions of surface and subsurface temperature fields, fronts and eddies, ocean circulation, sea states, and ice coverage
- Optimum aircraft path and ship track routing
- Search and rescue forecasts.

FNMOC has a staff of 300 and an annual budget of about $22 million.

NOAA's **National Weather Service Weather Forecast Office (WFO)** recently relocated to Monterey to provide comprehensive public weather and flood warning and forecast services for a 150-mile radius area centered on Monterey Bay. NOAA's WFO provides watches and warnings for the general public for severe local storms and floods, local aviation watches and warnings, terminal forecasts and domestic aviation enroute forecasts, and marine warnings and forecasts for coastal areas. FWO has a staff of 45 and an annual budget of about $2.5 million.

Monterey Bay National Marine Sanctuary Office. In October 1992, the Monterey Bay National Marine Sanctuary was dedicated. It is the nation's largest at 5,300 square miles and extends from San Francisco Bay south to Cambria. The sanctuary program's goal is to provide an integrated program of resource protection, research, and education to assist in the long-term management. Resource protection efforts involve cooperation with other federal, state, and local agencies in formulating germane policies and procedures. To that end, a broadly based Sanctuary Advisory Council has recently been established. Also, an education program has also been developed which is directed towards improving public awareness of the sanctuary's resources and their wise use. Additionally, a research plan has been developed that focuses on enhancing the knowledge of sanctuary resources so that improved management decisions can be made. The santuary office has a staff of five and an annual budget of about $600,000.

Monterey Marine Resources Laboratory of the California Department of Fish and Game has conducted marine research and management activities in the Monterey Bay area since the 1930s. The mission of the laboratory is to document and manage the living marine resoures and the habitats on which they depend for their ecological value and for their use and enjoyment by the public. Objectives include:

- Continued existence of all marine species
- Recognition of the aesthetic, educational, scientific, and non-extractive uses of the area's living marine resources
- Protection of these resources from the effects of pollution and other human activity
- Management of marine fisheries including reasonable sport fisheries and local commercial fisheries and marine aquaculture in a manner consistent with other objectives.

These objectives are carried out through a program of monitoring of fisheries; documenting the "take" of target and non-target fish, seabirds, and mammals in nets; monitoring of sea otter populations; and provision of information for enforcement of pollution control sections of the Fish and Game Code. It has a staff of 25 and an annual budget of about $1.25 million.

Marine Pollution Studies Laboratory (MPSL) of the California Department of Fish and Game is the state's major facility for researching the effects of pollutants on living marine resources and commercial and sport fisheries. This program is spread over four sites in the Monterey Bay area, each focused on different aspects of pollution:

- *Institute of Marine Sciences*—evaluation of biochemical toxicology of marine organisms including the detoxification and intoxication mechanisms of oil spill dispersants and other pollutants (organochlorine pesticides)
- *Long Marine Laboratory*—organic chemical concentrations in marine biomonitoring organisms, sedi-

[illegible] potential impacts on marine organisms for both toxicity testing and marine pollution monitoring

- *Moss Landing Marine Laboratories*—analysis and monitoring of contaminants in biomonitoring organisms and sediments (California Mussel Watch) and assessment and cleanup of contaminated sediments in bays and harbors
- *Granite Canyon*—effects of municipal and industrial waste discharge and contaminated sediments of kelp, fish, mollusks, and crustaceans with the goal of establishing enforcement standards and criteria for state and federal water regulations. Developing methods and conducting marine toxicity tests of oil dispersants for establishing criteria and standards of licensing of oil-spill clean-up products.

MPSL has a staff of 32 and an annual budget of about $2.6 million.

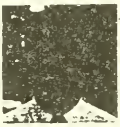
National Marine Fisheries Service's Southwest Fisheries Center, one of four regional research centers, is responsible for biological and environmental research in laboratories in Honolulu (Hawaii), La Jolla, Monterey, and Tiburon (all in California). (The Tiburon Lab is planning to relocate to the Long Marine Lab site.) Specific objectives of the research program dealing with recreational and commercial fisheries include:

- Provide technical information needed by the Pacific Fishery Management Council to manage groundfish
- Develop the biological understanding of fish community dynamics necessary for multispecies management models of Pacific Coast groundfish
- Understanding the functional relationship between fishes and their host environments such that the inherent and environmental factors that influence fish population production and persistence can be identified, described, and predicted
- Increase the productivity of California fisheries by promoting the use of under-utilized resources and increasing the efficiency of existing harvesting and processing methods.

The staff numbers 28 and its annual budget is about $1.6 million.

An Emerging National Center

Monterey Bay is emerging as a national center for marine and environmental research by virtue of the unique character of the bay, its topography, water, and life and because the programs and reputations of those marine institutions surrounding the bay continue to attract new agencies and programs. The diversity of programs, institutions, and scientists located on the bay margins is probably unique in the world. In response to the global environmental issues, as well as state and federal research initiatives and directives of the 1990s, the diversity has led to expanded interaction and collaboration. The combination of government agency programs and educational/research institutions in close proximity has encouraged cooperative research efforts and collaboration that are increasing and proving to be mutually beneficial. Such interactions, as well as shared personnel, facilities, laboratories, and research vessels, enables more economical operations. The program directors and their scientists are showing that cooperation and collaboration rather than competition are the hallmarks of the region's successful efforts. The future of marine research and education around Monterey Bay looks very bright. /st/



Dr. Gary B. Griggs, a professor of Earth Sciences at UC/Santa Cruz for 26 years, has served as chairman of the department. His research and teaching included geological hazards, coastal processes, and coastal engineering and most recently on coastal hazards and land-use planning, shoreline erosion, and coastal protection structures. For 15 years Griggs was geological advisor to Santa Cruz County and has consulted widely. He has published 95 articles and four books.

Congressional Briefing on Oceanography
Santa Barbara, California
February 12, 1996
Comments by Curtis A. Collins, Professor of Oceanography, Naval Postgraduate School,
Monterey, California

Congressmen, Ladies and Gentlemen:

I begin by noting that these remarks are my own observations and opinions and should not be construed as representing either the official view of the US Navy nor those of the Superintendent and Academic Dean of the Naval Postgraduate School. I will focus my remarks on the themes of federal, state and industrial consortia, and ways in which I feel the US Navy and the Naval Postgraduate School can take advantage of such arrangements.

1. **Educational Consortia for Monterey Bay Area.** In ocean sciences, the academic and research institutions in the Monterey Bay area have developed complementary programs in different subdisciplines. For example, the Naval Postgraduate School specializes in Physical and Acoustical Oceanography while Moss Landing Marine Laboratories (MLML) (part of the California State University system) specializes in Biological and Chemical Oceanography. The institutions in the Monterey Bay area (University of California, Santa Cruz (UCSC), Hopkins Marine Station of Stanford University, MLML, and Monterey Bay Research Institute (MBARI)) are in the process of forming an educational consortium. For example, arrangements for students at UCSC to take classes at NPS, and vice-versa, have been completed. This consortia will allow students and faculty to take advantage of academic expertise and facilities at existing campuses so that laboratories and classes need not be duplicated. I believe that this consortia is important for NPS in the area of ocean sciences. Future NPS students (US Navy officers) will need education in areas of geological, chemical and biological oceanography. Rather than hiring faculty and building laboratories for studies in these areas, it makes more sense for NPS students to enroll in these courses at neighboring institutions. Note that the current law provides severe restrictions upon civilian students enrolling in classes at NPS, and effectively precludes NPS participation in this consortia. Congressman Farr has introduced legislation to correct this situation and I encourage your support.

2. **Research Vessel Utilization**. Dr. Baker has already told you of his concerns regarding support for the oceanographic research fleet. The US Navy has done an excellent job of providing ships for use by the academic community, but I think that the Navy could do a better job of utilizing the ships operated by academic institutions. The best Navy example of utilization of these ships is the Office of Naval Research which routinely uses academic research ships for the Naval Research Laboratory as well as contract programs in basic research.

In the case of applied research (tasks such as sensor or model validation), funding for ship needs within the Navy is almost non-existent. This is in part due to the disappearance of the pool AGORs, *USNS DeSteiguer, Bartlett,* and *Lynch*, which had traditionally fulfilled these needs. Research vessels operated by academic institutions could readily meet these applied research needs of the Navy but a source of funding needs to be found. Similarly, for validated operational requirements, I believe that the academic fleet could meet Navy needs in some instances, at a substantial cost saving to the Navy.

An example of utilization of academic ships and federal/state/private consortia is the Central California Consortium. Ten years ago, NPS and MLML operated small (~85 foot) ships with limited capability and decided, with other institutions in the area, to try to acquire a larger, more capable research vessel. With full support of the Navy, a 135-ft vessel was assigned to CENCAL, operated by MLML (California State University), with the Navy providing $500,000 per year for utilization of the ship by NPS students and faculty. But this story may turn out to be a cautionary one for such consortia: the Navy has been able to identify only $67,000 for FY96 operations.

3. **Global Observing Programs**. Lt. Matthew Fontaine Maury, USN, established the original global ocean observing program in 1855 when he convinced mariners to systematically observe winds and currents and provide copies of these observations to the Bureau of Charts and Navigation in exchange for Pilot Charts which showed winds and currents based upon compilations of these data. Adm. Watkins has previously provided you with information regarding a new attempt to organize a Global Ocean Observing System. Because the interior of the ocean is opaque with respect to electromagnetic radiation, shipboard observations are required in any global census of the ocean's currents and waters. I believe that the US Navy (and other navies of the world) can play an essential role in this program by taking advantage of a new generation of shipboard ocean observing systems. There are two reasons why this is advantageous.

First, Navy ships employ advanced technology with well trained and educated crews. Second, Navy ships often operate in areas not frequented by other ships.

4. **Classification Issues.** Adm. Watkins has also noted the value of a number of Navy data sets with respect to ocean research and has asked that consideration be given to their declassification in a manner consistent with the legitimate security needs of the United States. My observation is that it is very difficult to get anything declassified from the bottom-up, and I want you to know that we very much appreciate continued Congressional pressure to release these data sets when there are no reasons for their classification.

Although the ocean is opaque with respect to electromagnetic radiation, it is nearly transparent to acoustic energy: an 80 second pulse of 260 Hz sound with 15 watts of energy can be detected to ranges in excess of 1000 km. This makes the acoustic ocean surveillance assets (SOSUS stations) of the US Navy exceedingly valuable as ocean observatories. They can be used for such diverse activities as listening to and tracking marine mammals, monitoring thermal plume activity at submarine ridges, tracking lagrangian floats, and, with tomography techniques, studying the ocean's response to seasonal changes of wind stress, etc. The success of such studies requires regular, routine access to the data collected at the SOSUS stations.

NPS has recently acquired the SOSUS station at Point Sur, California. It has not been actively used by the Navy for many years. We have formed a partnership with MBARI to exploit acoustic data from this SOSUS array for ocean research and education. We would not only like to use these data for research and education, but we would also like to make these data available to the community in real time over the internet. We are currently trying to get permission to do this. One problem, of course, is that it raises the possibility of some other country tracking or listening to USN submarines using US listening arrays, which really is unacceptable. But nevertheless, when there are no USN submarines in the area, and US security cannot be threatened, we would like to be able to easily use these data for research and instruction. The potential of these acoustic data for improving our understanding of Eastern Pacific Ocean is unlimited.

5. **Deep Ocean Waste Disposal Sites.** I believe that an excellent opportunity to develop federal-private partnerships exists in the area of ocean waste disposal and remediation. Although no longer used, a number of hazardous waste disposal sites exist along US. coasts which offer a valuable opportunity for long-term environmental studies as well as development of remediation techniques. Commercial applications of related

technologies readily exist, and US law permits deep ocean disposal of fly ash, sewage, and uncontaiminated dredge spoils.

An example of a hazardous waste disposal site is the area to the west of the Farallones (located within the current marine sanctuary) where the AEC and USN dumped at least 47,000 barrels of low level radioactive waste, some of which ended up in water only 350-700m deep. The dumping was done in the late 1950's and early 1960's, and much of the Navy waste consists of scrapings from vessels involved in bomb tests. There have been few visits to the dump site area, and it is difficult to know the extent to which the ocean has been contaminated by leaking barrels. Interest in this site extends from local and state agencies, to DOE, NOAA, EPA, and USGS.

The US Navy possesses unique and valuable resources for deep ocean operations, both within the Submarine Development Group and at the Naval Oceanographic Office. A good example of this capability is the current recovery of flight data recorders from the aircraft that recently crashed in the Caribbean. The Navy experience includes work with high level radioactive materials and munitions. The utilization of these assets to develop remediation, recovery and disposal techniques, and to transfer these methods to private industry is important. Continued utilization of the oceans will offer instances where remediation and clean up of deep ocean sites will be necessary.

I have offered a few examples of utilization of Navy and NPS assets in consortia of public and private institutions in order to better understand and utilize the ocean. CORE and Adm. Watkins have done a tremendous job in providing you with an agenda for these activities. I want to thank you for the opportunity to make these remarks.

Hydrocarbons in the marine environment: relationships between natural hydrocarbon seepage and oil production

Dr. Bruce P. Luyendyk, Director, Institute for Crustal Studies, Dept. of Geological Sciences, University of California, Santa Barbara, CA 93106 luyendyk@crustal.ucsb.edu

Dr. J. Scott Hornafius, Geologist, Mobil Oil Corp. and visiting Research Scientist, Institute for Crustal Studies, Dept. of Geological Sciences, University of California, Santa Barbara, CA 93106, hornafiu@crustal.ucsb.edu

Dr. Libe Washburn, Associate Professor, Institute for Computational Earth System Science, Dept. of Geography, University of California, Santa Barbara, CA 93106, washburn@icess.ucsb.edu

Dr. Alain F. Trial, Post Graduate Researcher, Institute for Crustal Studies, Dept. of Geological Sciences, University of California, Santa Barbara, CA 93106, trial@magma.geol.ucsb.edu

Dr. Sanjoy Banerjee, Professor, Dept. of Chemical and Nuclear Engineering, University of California, Santa Barbara, CA 93106, sanjoy@squid.ucsb.edu

Good afternoon ladies and gentlemen. My name is Libe Washburn and I am an associate professor in the Geography Department at UC Santa Barbara. My field of study is physical oceanography with an emphasis on interdisciplinary research issues. Thank you for giving me the opportunity to discuss some of the oceanographic research that my colleagues and I are conducting at UCSB. For the past year I have been involved in a multidisciplinary study of natural hydrocarbon seepage in the Santa Barbara Channel that is being conducted by the Institute for Crustal Studies at UCSB. The overall study involves the participation of six faculty members and six graduate and post-graduate researchers at UCSB. Participants in the study come from four university departments and cover the fields of oceanography, geophysics, remote sensing, biology, and chemical engineering. Participants in the study also come from industry. One participant is a geologist from Mobil Oil Corporation who is a visiting research scientist at UCSB. We are also working with private companies that have expertise in specialized techniques for detecting hydrocarbons in seawater and who have important baseline data for detecting changes in the marine environment.

We think this work is an example of the innovative research that can be pursued by the academic community in cooperation with the private sector. The initial results of our study are unexpected and we think you will find them interesting. However, you should bear in mind that this is on-going research and we are actively involved in field studies, data analysis, synthesis of historical records, and careful searches for existing scientific literature. Our work has been funded through the peer-review process and results from our research will be published in the peer-reviewed literature.

The preliminary findings of this work indicate that there has been a reduction in natural hydrocarbon seepage over the past twenty years near an offshore oil platform in the Santa Barbara Channel. This reduction has occurred during a time of oil production at the platform and we hypothesize that this production has lowered natural seepage rates. We are working to verify this hypothesis and to accurately quantify changes that have occurred. We are also working to understand the implications of our findings. To the best of our knowledge, this is the most detailed study to ever examine a change in seepage over time in the marine environment.

I will continue my presentation by showing you some of the evidence that a reduction in hydrocarbon seepage has occurred. I will end by elaborating on the possible consequences and significance of this finding.

The Santa Barbara Channel is an area of intense natural hydrocarbon seepage (Wilson et al., 1974 and Allen et al., 1970). As far as we are aware, the only area of greater natural marine seepage in the world is in the Caspian Sea in the former Soviet Union. The abundant tar found on southern California beaches is due to this natural seepage. All of the tar on Santa Barbara's beaches and half of the tar on Los Angeles beaches comes from the natural seeps offshore from Coal Oil Point (Hartmond and Hammond, 1981), near the UCSB campus. The volatile hydrocarbons from these seeps are also a significant source of air pollution in Santa Barbara and Ventura Counties (Killus and Moore, 1991). The smell of hydrocarbon compounds from the natural seeps is often present on the UCSB campus.

Our research group has been studying these seeps in order to quantify the total amount of hydrocarbon emissions and to determine if there has been any change in emissions due to offshore oil production. Each oil field in the Santa Barbara Channel has some associated natural hydrocarbon seepage. This **figure (#1)** shows the oil fields in the Santa Barbara Channel. We have focused our initial efforts on the seeps above the South Ellwood Offshore Field, because the seeps are extremely intense at this location. There is also an offshore platform that has been producing oil from a portion of the natural seep field since 1967. The seepage is coming from oil in the Monterey Formation, which has been produced from Platform Holly since 1972.

This **figure (#2)** shows a map of the seep activity on the South Ellwood Field in 1994 that was measured with a sonar survey. The total gas seepage from this field is about 5 million cubic feet per day. In addition, about 6 thousand gallons of oil is naturally seeping into the ocean every day. About 8% of the gas seepage is being captured by seep containment devices ("seep tents") that were placed on the seafloor one mile east of Platform Holly in 1982. The surprising result of this survey is how little seepage was occurring within one mile of Platform Holly in 1994 and 1995. The area around Platform

Holly had been thoroughly documented as an area of intense seepage by oil industry surveys in the 1940's, 1950's, and 1970's (Fischer and Stevenson, 1973). Based on this finding, a research grant was obtained from the University of California's Energy Study Program to acquire new high-resolution seismic data in 1995 to compare with data obtained in 1973. The next overhead shows a comparison of data acquired between Platform Holly and the seep tents in 1973 and 1995.

The top of this **figure (#3)** shows the intense seepage around Platform Holly that was recorded by an acoustic survey in 1973. The figure shows dark areas in the water column that correspond to rising plumes of bubbles. The bubbles themselves are composed mostly of methane, but also contain ethane, propane, and other constituents. The bottom of the figure shows the seep activity in 1995 along the same line. Note the dramatic reduction in seepage that has occurred over this section which covers a horizontal distance of about one mile. Quantitative analysis of this data indicates about a 90% reduction in seepage within one mile of Platform Holly over the past 22 years. The area around Platform Holly is the only area that has experienced a reduction in seepage, based on our geophysical surveys. The reduction in seepage around Holly may result from a reduction in reservoir pressure due to withdrawal of oil.

Another line of evidence indicating a decreasing seepage rate around Platform Holly comes from oceanographic surveys which measure dissolved hydrocarbon concentrations in the ocean downcurrent from the seep field. The dissolved concentration can be used as a measure of seep activity, because seep gases partially dissolve in the ocean as they rise from the seafloor (Fischer, 1978). Dissolved hydrocarbon components are carried downcurrent, where they have been measured in past surveys. In 1995 we measured dissolved hydrocarbon concentrations in an area that was surveyed in 1981 by InterOcean Systems, Inc. of San Diego California. We have been working with InterOcean in the synthesis of these data sets. This **figure (#4)** compares propane concentrations between 1981 and 1995. The peak concentrations measured in 1981 were nearly ten times as high as in 1995. Although ocean currents also influence hydrocarbon concentrations, this is a larger reduction than can probably be accounted for by currents alone. However, we are collecting oceanographic measurements and are using computer models to understand the effects of currents on the concentrations. Some of the data that we are using in our analysis has been generously supplied by the Coastal Oceanography Group at the Scripps Institution of Oceanography. Our observation of a change in dissolved hydrocarbon concentrations is consistent with a decrease in seep activity since 1981.

If the hypothesis that oil production has reduced natural hydrocarbon seepage is true, then some local and national implications need to be explored. At the local level, reduced seepage will lower the total amount of reactive organic gases released into the atmosphere offshore from Santa Barbara. It will also lower the amount of tar and oil in local waters. Reactive organic gases are precursors to smog-forming ozone which is a health hazard. Tar and oil wash up on our beaches and diminish their recreational and aesthetic values.

Results from our research may have national significance as well. They suggest that reductions in natural seepage due to oil production must be accounted for when determining greenhouse gas emission inventories. Methane is a greenhouse gas that is 20 to 30 times as potent as carbon dioxide. Around Platform Holly methane emission due to natural seepage has decreased by about 15 to 25 tons per day. This decrease is equivalent to 12-20% of the global warming potential produced by burning the oil that comes from this field each day. The reduction in natural seepage may persist after oil production has stopped and a key research issue is understanding the long term relationship between oil production and natural seepage.

We emphasize that our study is focused on a small region around a single platform. It is not known if the changes in seepage rates at the South Ellwood Field are typical of other oil fields around the world. To the best of our knowledge, there is no research directed at understanding changes in natural hydrocarbon seepage around oil fields, either in the United States or overseas, except at Platform Holly. We feel that interdisciplinary studies spanning the areas of oceanography, geophysics, geology, biology, and climatology are necessary to understand the global significance of this issue.

In summary, we feel that our project is a good example of a cooperative research effort being conducted by members of the scientific community and industry. It also illustrates how basic scientific research can produce in practical results with policy implications. Thank you for your attention.

References

Allen, A.A., R.S. Schueter, and P.G. Mikolaj, 1970. Natural oil seepage at Coal Oil Point, Santa Barbara, California, Science, v170, p.974-977.

Fischer, P.J., 1978. Oil and tar seeps, Santa Barbara Basin, California, *in* California Offshore Gas, Oil, and Tar Seeps, California State Lands Commission, Sacramento, California, p.1-62.

Hartman, B., and D. Hammond, 1981, The use of carbon and sulfur isotopes as correlation parameters for the source identification of beach tar in the Southern California Borderland, Geochim. et Cosmochim. Acta, v45, p.309-319.

Killus, J.P., and G.E. Moore, 1991. Factor analysis of hydrocarbon species in the south-central coast air basin, J. of Applied Meteorology, v30, p.733-743.

Wilson, R.D., P.H. Monaghan, A. Osanik, L.C. Price, and M.A. Rogers, 1974. Natural Marine Oil Seepage, Science, v.184, p.857-865.

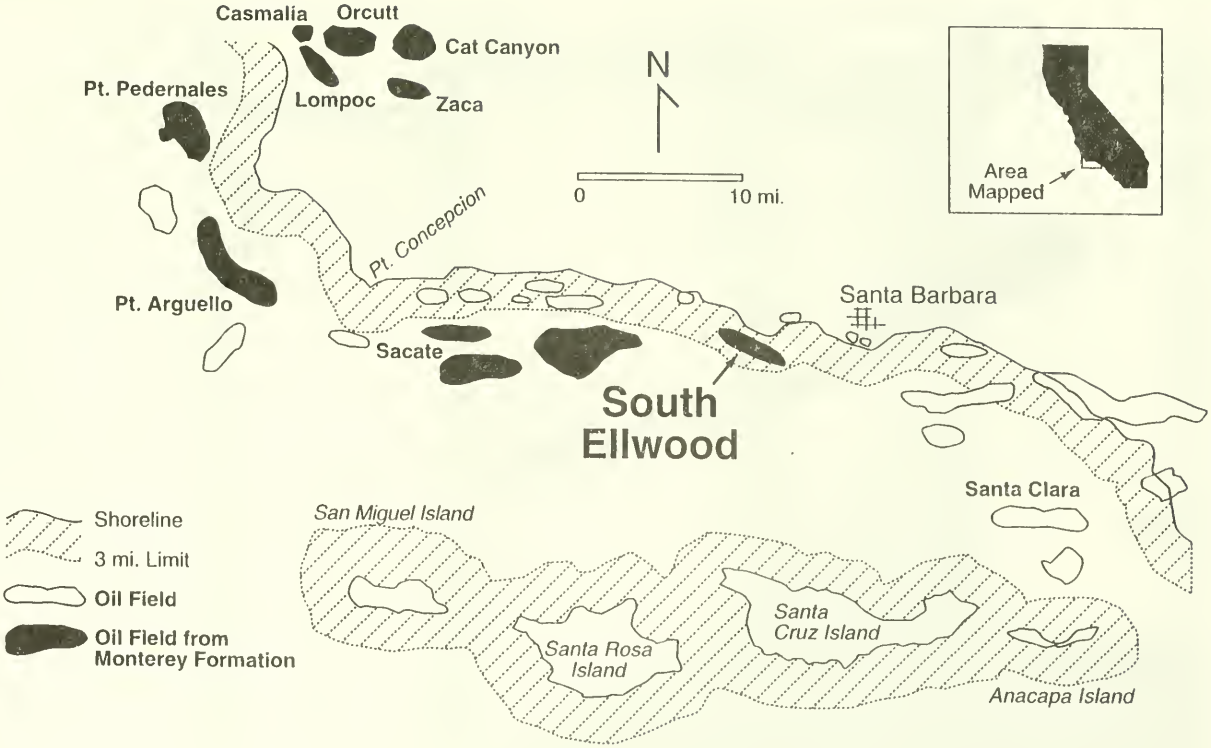


Figure 1. Oil fields in and around the Santa Barbara Channel.

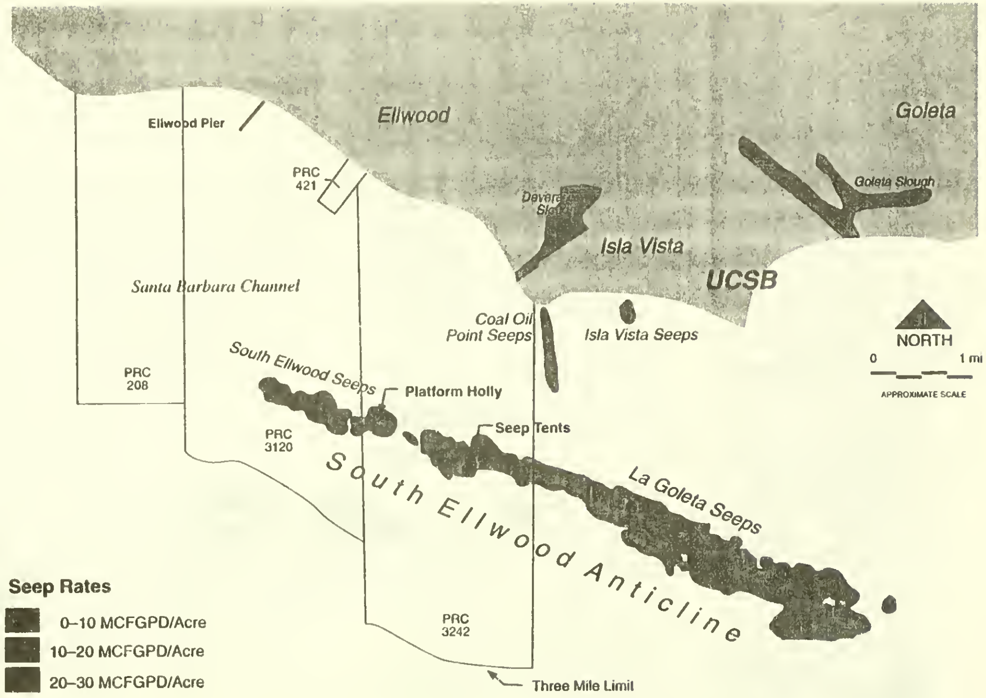


Figure 2. Hydrocarbon seepage rates on the South Ellwood offshore oil field. Data obtained in 1994 by the Institute for Crustal Studies, UCSB. Units are thousands of cubic feet of gas per day per acre (MCFGPD).

Acoustic Image of Seep Activity

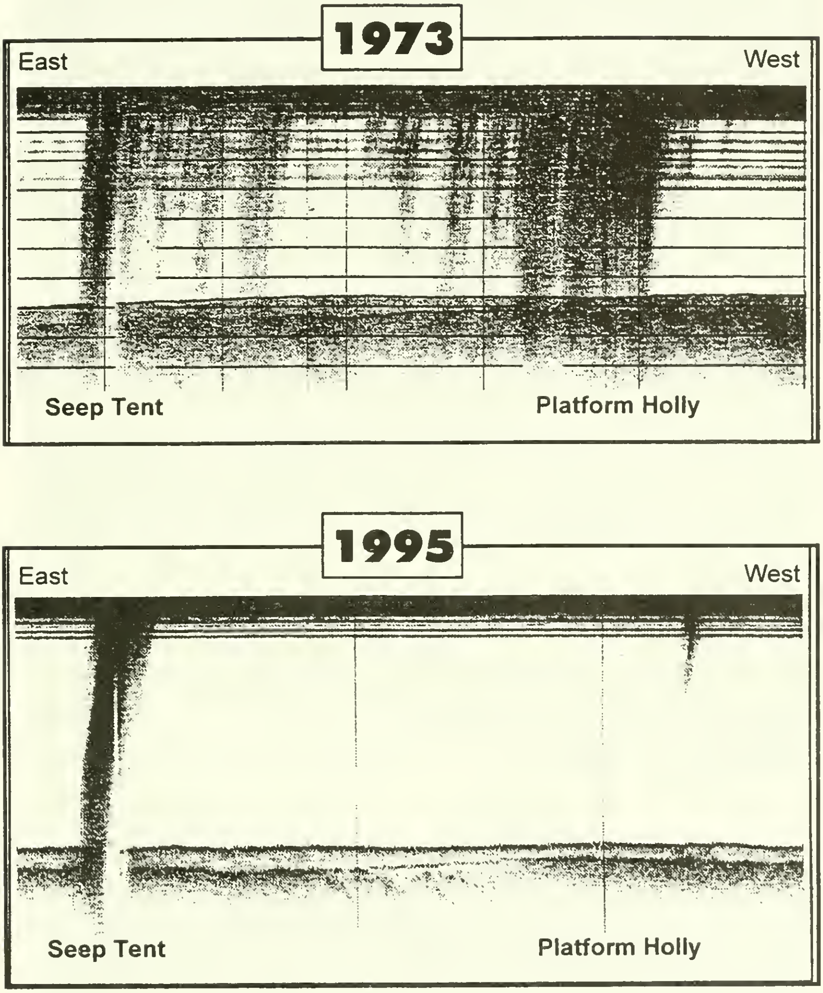


Figure 3. Seep activity in 1973 compared with 1995. Dark columns show rising bubble plumes of seep gases. Distance between Platform Holly and Seep Tents is approximately 1 mile.

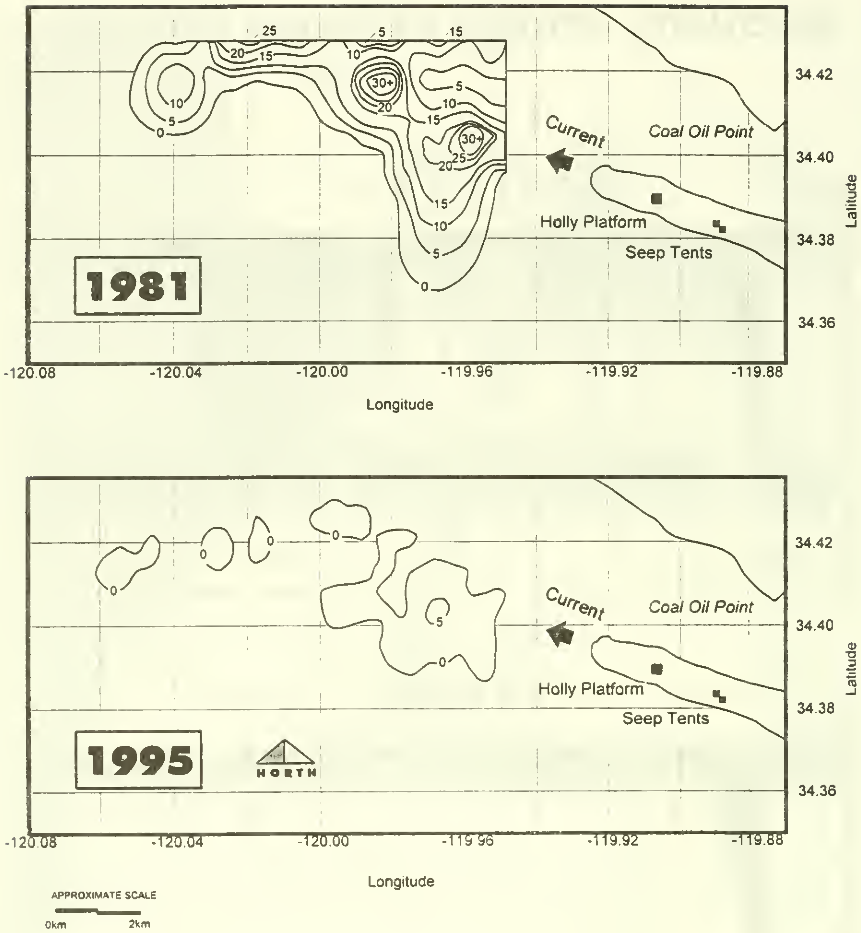
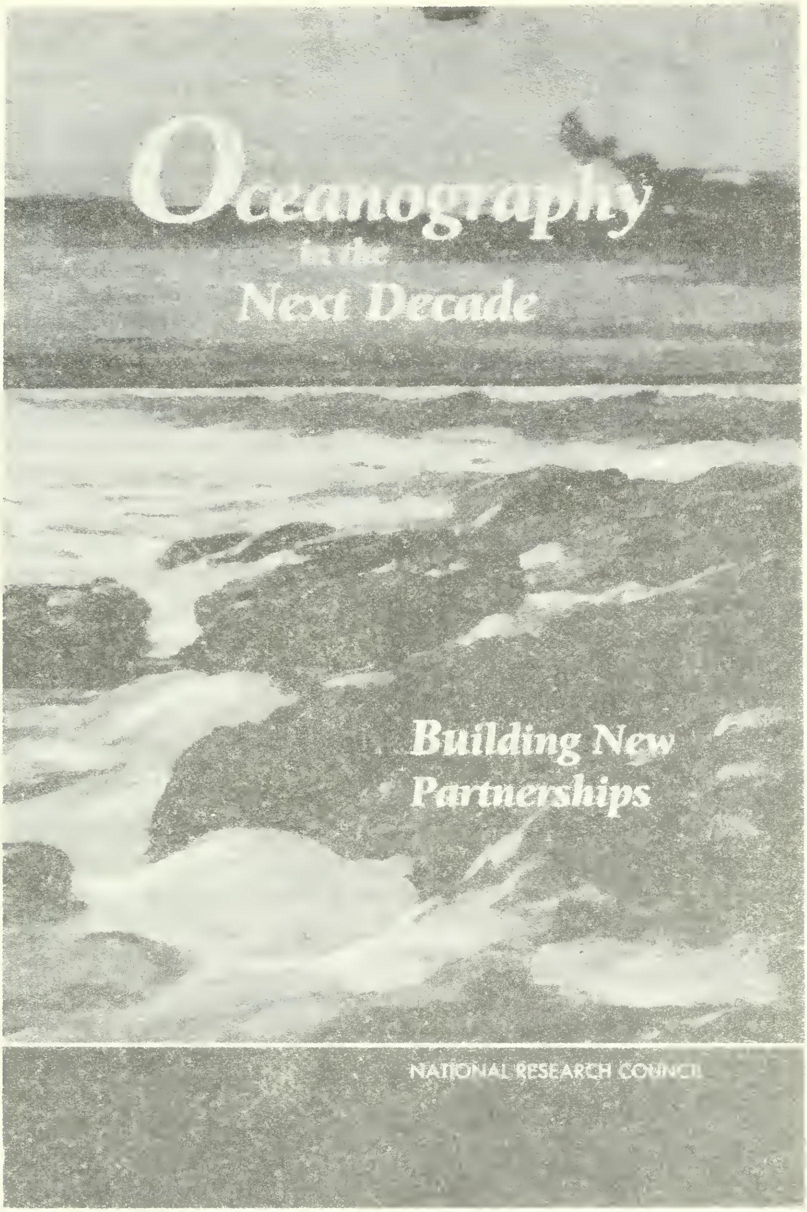


Figure 4. Oceanic concentrations of dissolved propane over the South Ellwood field in 1981 compared with 1995. Contour levels are shown in parts per million.



Oceanography in the Next Decade

Building New Partnerships

NATIONAL RESEARCH COUNCIL

Oceanography in the Next Decade

Building New Partnerships

Ocean Studies Board
Commission on Geosciences, Environment, and Resources
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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The ocean has always had a profound influence on human life and activities. It has been an important source of food and means of commerce. However, it has also been a threat to human life as a focus of war and through its encroachment onto land. In recent decades, the United States has been the world leader in ocean research, both in basic studies and research on the ocean's practical influence on human activities. This pioneering work has largely been the result of remarkably successful partnerships between Federal agencies and research in universities, in which federal agencies support the research of academic scientists and academic scientists provide advice on internal and external research by a variety of mechanisms.

However, the world in which these partnerships were created and sustained is changing rapidly. Concerns about the ocean as a medium for warfare and as a threat to national security are decreasing while environmental problems of the coastal zone and understanding how the ocean controls climate are of increasing importance. Also, major advances in understanding the ocean and in the development of technologies for observing it have set the stage for much greater research achievements. But the potential for such achievement must be set against the human and financial costs of sustaining science. For we are now in a period in which the importance of better understanding the ocean is ever more clear while the resources necessary to obtain this understanding are increasingly scarce.

To understand better what types of partnerships would best serve the United States in the years to come, the Ocean Studies Board of the National Research Council undertook a study of where marine science stands today, how we arrived in this position, and where marine science and technology appear to be headed. This report establishes a framework, in which improved partnerships between the federal government and academic researchers can sustain the advances of the past, and lead our country and the world to greater understanding of the many roles the ocean plays in human life. In their report, the Ocean Studies Board recognizes the ever-growing urgency of the applications but also emphasizes the importance of maintaining the health of the basic science on which all policy decisions must be ultimately based. Although obtaining the proper balance in research funding is essential to national security--in its broad sense--it will not be easy. The Board recommends the use of series of coordinated federal-academic partnerships to achieve a balance in funding among the agencies and a corresponding vitality in basic and applied ocean research.

This report is the result of the work of many groups and individuals who served as participants in the study, writers of drafts of the report, or as reviewers. The study was begun under the direction of John Sclater, then chairman of the Ocean Studies Board, and completed under the OSB chairmanship of Carl Wunsch. William Merrell chaired this study during its final 9 months, seeing the report to its completion. I thank the chairmen, Board members, and other participants for their efforts in producing a comprehensive report on the future of marine sciences and technology in the United States. I find the call for new and improved partnerships between federal agencies and academia especially timely and believe that the report provides a solid base for building future programs in marine sciences.

In 1991, oceanography reached the end of an era when two major figures passed from the scene. The Ocean Studies Board dedicates this report to Roger Revelle and Henry Stommel, who recognized decades ago the kind of science that would be needed to understand the biology, chemistry, and physics of the ocean and their impact on the Earth system.

Frank Press

Frank Press
Chairman
National Research Council

Preface

The field of oceanography has existed as a major scientific discipline in the United States since World War II, largely funded by the federal government. In this report, the Ocean Studies Board documents the state of the field of oceanography and assesses the health of the partnership between the federal government and the academic oceanography community.

The objectives of the report are to document and discuss important trends in the human, physical, and fiscal resources available to oceanographers, especially academic oceanographers, over the last decade; to present the Ocean Studies Board's best assessment of scientific opportunities in physical oceanography, marine geochemistry, marine geology and geophysics, biological oceanography, and coastal oceanography during the upcoming decade; and, to provide a blueprint for more productive partnerships between academic oceanographers and federal agencies.

The study's approach was to document trends in resources over the past ten to twenty years and to speculate on the likely directions of oceanographic science over the next decade. The board used a number of means to gather information from ocean scientists and from the agencies that conduct and fund ocean science. A meeting on the topic of oceanographic facilities was attended by a number of agency representatives to discuss agency provision and use of these facilities. In addition, agencies that employ oceanographers were surveyed to determined the human resources characteristics of the federal agencies now and over the past twenty years.

A similar questionnaire was sent to the institutional members of the Council on Ocean Affairs to assess the characteristics of the academic oceanography community. Agency and academic scientists were brought together on a number of occasions to discuss the resources available to the field and the science directions of the field.

The board convened two meetings on the future of oceanographic science, one on the West Coast and one on the East Coast. These meetings brought together groups of oceanographers balanced by scientific discipline and these meetings were used to discuss working documents on the exciting science directions of each of the disciplines. The Ocean Studies Board is grateful to those who took on the task of gathering the information for each discipline: Arnold Gordon (physical oceanography), Paul J. Fox and Charles Langmuir (marine geology and geophysics), John Edmond and John Hedges (chemical oceanography and marine chemistry), James Yoder (biological oceanography), and Kenneth Brink (coastal oceanography). Many other people too numerous to cite individually assisted in various aspects of the study, particularly board members who reviewed sections within their fields of expertise.

The board presented its preliminary findings at two meetings of the American Geophysical Union (AGU), one of the major scientific societies to which oceanographers belong. The purpose of the AGU special sessions was to get feedback from scientists in the field of oceanography, to ensure that the board's views were representative of the field as a whole. The first special session, on the topic of resources for oceanography, was held at the December 1990 AGU meeting in San Francisco, California. The second special session, which summarized the results of the two meetings on future oceanographic science, was held at the May 1991 AGU meeting in Baltimore, Maryland.

This study was funded by the agencies that support research in oceanography, including the National Science Foundation, the Office of Naval Research, the National Oceanic and Atmospheric Administration, the Department of Energy, the U.S. Geological Survey, and the National Aeronautics and Space Administration. The board gratefully acknowledges the efforts of the staff of the Ocean Studies Board who labored with the board to produce this report, particularly Mary Hope Katsouros, Edward R. Urban, Jr., Rebecca Metzner Seter, Robin Rice, and David Wilmot. The editor of the report was Sheila Mulvihill.

William J. Merrell
Study Chair

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Oceanography
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The Federal Government and academic institutions have together built a research enterprise that is without peer in the world. This enterprise has been based on the concept of a partnership, where each partner contributes and each benefits. But, as in any partnership, a periodic and thorough reexamination is both healthy and necessary, if only to revalidate the original conditions of the partnership.

(p. 138 in Office of Management and Budget, 1992)

Summary

Federal agencies and the academic oceanography community have been fortunate to work together in productive partnerships. These mutually beneficial partnerships are characterized by the federal agencies' funding research at academic institutions that is important to the agencies' missions or is critical to maintaining the health of the basic ocean research endeavor.

These partnerships are likely to change because oceanography is developing a new focus as the results of oceanographic research become increasingly relevant to social and economic concerns. There is an increasing emphasis on global-scale and multidisciplinary research, and a changing mission profile of naval oceanography. Ocean research programs that developed primarily from scientific curiosity have attained increased social meaning and urgency, and federal agencies are increasingly pressured to produce cogent policy options. Yet, over the past decade, academic oceanographers have had access to increasingly limited resources compared to their overall capacity to conduct scientific research. The number of Ph.D.-level academic oceanographers increased dramatically between 1980 and 1990. Also, more sophisticated instrumentation and improved data handling and computing techniques have increased both the scientific capacity of each researcher and the cost of each investigator's research. The net result is a serious imbalance between what can be accomplished and the available resources. Fiscal support in the United States has not kept up with scientific progress, whereas other countries have increased their capacities to conduct oceanographic research. To respond to these challenges, federal agencies and the academic oceanography community need to establish productive new partnerships. Key elements in such partnerships are encouraging individual scientists to take intellectual risks in advancing basic knowledge, providing support that is tied to solving present problems, and encouraging scientists to cooperate in the development of large shared research endeavors. These new partnerships will be the basis of a national oceanographic effort that balances the necessity for a robust program in basic research against the need for research directed at important societal problems.

This report has three major objectives. The first is to document and discuss important trends in the human, physical, and fiscal resources available to oceanographers, especially academic oceanographers, over the last decade. The second goal is to present the Ocean Studies Board's best assessment of the scientific opportunities in physical oceanography, marine geochemistry, marine geology and geophysics, biological oceanography, and coastal oceanography during the upcoming decade. The third and principal objective is to provide a blueprint for more productive partnerships between academic oceanographers and federal agencies. The board attempts to do this by developing a set of general principles that should provide the basis for building improved partnerships and by discussing critical aspects of the specific partnerships for each federal agency with a significant marine program.

OCEANOGRAPHY AND SOCIETY

The ocean dominates Earth's surface and greatly affects daily life. It regulates Earth's climate, plays a critical role in the hydrological cycle, sustains a large portion of Earth's biodiversity, supplies food and mineral resources, constitutes an important medium of national defense, provides an inexpensive means of transportation, is the final destination of many waste products, is a major location of human recreation, and inspires our aesthetic nature.

Today's sense of urgency about ocean studies is precipitated by human impacts on oceanic systems and the need for a better understanding of the ocean's role in controlling global chemical, hydrological, and climate processes. The nation is faced with pressing marine research problems whose timely solution will require increased cooperation between federal agencies and academic scientists. Many of these problems arise from the need to accommodate multiple uses of the ocean and from the ever-increasing concentration of the U.S. population near our coasts. Oceanographic research is important to many of the nation's social concerns, including the following:

- *Global Change.* The ocean is key to regulating both natural and human-induced changes in the planet. The role of ocean circulation and the coupling of the ocean and atmosphere are basic to understanding Earth's changing climate. Regional events such as El Niño and ocean margin and equatorial upwelling influence climate on both seasonal and longer time scales. Earth's population is now large enough to alter the chemical composition of the ocean and atmosphere and to impact the biological composition of Earth.
- *Biodiversity.* The ocean comprises a large portion of Earth's biosphere. It hosts a vast diversity of flora and fauna that are critical to Earth's biogeochemical cycles and that serve as an important source of food and pharmaceuticals. In addition to the exciting discoveries of previously unknown biota near hydrothermal vents, many deep-ocean organisms have evolved under relatively stable conditions. Their unique physiologies and biochemistries have not yet been explored adequately, and methods for sampling the more fragile of these species have been developed only in the past decade. Human influence on marine biota has increased dramatically, threatening the stability of coastal ecosystems. Some species have been overharvested; others have been transported inadvertently to areas where they are not indigenous, sometimes resulting in deleterious effects on native species. Still other species are being cultivated commercially, and aquaculture facilities along coastlines are becoming commonplace in some countries. A better understanding of the ecology of marine organisms is urgently needed to prevent irreversible damage to this living resource.
- *Environmental Quality.* Waste disposed of in coastal areas has reached the open ocean, with broad ramifications for living resources. This problem is compounded because many marine species harvested for commercial and recreational purposes spend a portion of their lives in coastal waters and estuaries. Thus, local pollution can have far-reaching effects.
- *Economic Competitiveness.* Economic prosperity in a global marketplace depends increasingly on technical and scientific applications. There is concern about the ability of the United

States to compete with Europe and Asia. Basic and applied research in the marine sciences and engineering is necessary to achieve and maintain a competitive position in a host of fields, including marine biotechnology, aquaculture, hydrocarbon and mineral exploration and production, maritime transportation, fisheries, treatment and disposal of waste, and freshwater extraction.

- *National Security.* Unprecedented world political changes are redefining national defense interests and altering research and development priorities. Knowledge of the ocean, especially the acoustic properties of marginal seas and coastal areas, is critical to national defense. Experience gained in 1991 during the war in the Persian Gulf highlights the need for better information related to oceanic and coastal processes and to maritime operations and transportation.
- *Energy.* The ocean's energy resources are essential to the national economy and national security. After a decade of relative neglect, energy issues are reemerging. With oil supplies continually threatened by instability in the Middle East and with increasing atmospheric carbon dioxide viewed as a possible trigger of global warming, there is a need to look carefully at a full range of energy sources, from oil and gas in our Exclusive Economic Zone to wave and tidal power and ocean thermal energy conversion. Better knowledge of the ocean and seabed is necessary to exploit responsibly the ocean's untapped petroleum and natural gas resources.
- *Coastal Hazards.* This nation must improve its prediction and response to coastal hazards, both natural and human induced. Hurricanes Hugo and Andrew, two of the strongest hurricanes of the century, devastated parts of the U.S. East Coast. Their impact reinforced the need for better predictive capabilities and a better understanding of coastal storm surges, flooding, erosion, and winds. The exploration for, and production of, petroleum and the transportation of petroleum and chemical products pose risks to the environment when spillage occurs. The movement, effects, and ultimate fates of spilled products must be understood for effective public response. The available information is woefully inadequate, particularly for fragile ecosystems such as coral reefs.

Policy decisions concerning these and many other marine research issues require a comprehensive understanding of the science and engineering of the ocean. Federal, state, and local policies should be based on the best available knowledge of how ocean systems work—their biology, chemistry, geology, and physics. Research results must be communicated effectively to policy makers, with gaps and uncertainties stated clearly and fairly. Also, basic understanding must continue to improve.

MAINTAINING EXCELLENCE

Since World War II, the United States has been the world leader in oceanographic research. Maintaining this excellence requires a talented population of scientists, an informed and educated public, a society interested in and appreciative of new discoveries, open lines of communication between oceanographers and the scientific community at large, and the economic resources necessary to conduct oceanographic research. Continued excellence in oceanography is essential to our national interests and requires constant improvement of both physical and human resources at academic oceanographic institutions. Solving both short- and long-term societal and environmental problems will require well-trained and dedicated scientists working in modern, well-equipped institutions, with sufficient funding. It is critical to the vitality of the ocean enterprise to continue nurturing the academic research environment in which students learn by performing research under the guidance of professors at the forefront of oceanographic science and engineering.

FUTURE OF OCEANOGRAPHIC SCIENCE

Oceanography, the science of the sea, serves many purposes while deriving its impetus from many sources. All of oceanography—physical, chemical, geological, and biological—is driven by scientists interested in advancing basic knowledge. During the past 30 years, marine scientists have verified that Earth's crust is divided into moving plates created at mid-ocean ridges and recycled back into Earth's interior at subduction zones. More recently, dense colonies of animals and bacteria have been discovered at some deep-sea hydrothermal vents and hydrocarbon seeps in ecosystems that only indirectly depend on energy from the Sun. Satellite observations have made possible global estimates of important ocean parameters, such as primary productivity. Our knowledge of interannual climate variations has improved to the point that scientists are now able to forecast El Niño climate disturbances months in advance. These are but a few of the discoveries that have characterized oceanography since the Second World War.

Over the next decade, the field will continue to provide exciting discoveries that contribute to an understanding of Earth as an integrated system and help unravel how humankind may be altering the system. It is now essential and possible to study marine processes on a global scale. Progress in oceanography over the next decade will occur both in the traditional marine science disciplines and, significantly, at the fringes and intersections of these disciplines. Multidisciplinary approaches will lead to new discoveries regarding the ocean's role in climate change, the hydrodynamics of mid-ocean ridges, and the dynamics of coastal processes. Comprehensive study of these topics will require unprecedented levels of cooperation among scientists from numerous disciplines.

Oceanographic studies in the coming decade will focus on how ecosystems affect global cycles of important elements and how changes in the global environment affect marine ecosystems. Studies of the planktonic food web in the sunlit surface waters will advance our understanding of such diverse issues as the role of the ocean in the global carbon cycle and the sustainable yields of commercial fisheries. Studies of ecosystems at deep-sea hydrothermal vents and hydrocarbon seeps will improve theories of the conditions under which life is possible and of the origins of life. More of the ocean will be explored to estimate the extent and nature of deep-ocean vents and their importance in global cycles. Continued study of the ocean's chemistry should bring new understanding of the past state of Earth, and of how marine processes operate today. The study of deep-ocean sediment cores will provide more information about past natural cycles of Earth's climate, against which present climate fluctuations can be calibrated. A better understanding of variability of the circulation of the world ocean, which transports water from near the ocean's surface to deep oceans and back again, will improve our understanding of the variability of the transport of surface water to depth and the interactions with climate.

The foundation of oceanographic knowledge now used in making policy decisions was gained largely through investments in basic research over the past four decades. Oceanographers are privileged to participate in a science that is intellectually compelling and has immediate and long-term practical applications. Yet, the pressure for quick answers to practical questions sometimes obscures the need for investing in the improvement of basic science, which remains the key to solving long-term practical problems. Under pressure to provide immediate solutions, it is tempting for agencies whose focus is on their responsibilities for regulation and information provision (mission agencies) to concentrate only on these short-term aspects of their missions. Such mission agencies include the Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), parts of the National Oceanic and Atmospheric Administration (NOAA), and others, distinct from the longer-term focus of the National Science Foundation (NSF) and Office of Naval Research (ONR). However, the continued success of these mission agencies ultimately depends on the results of basic research, as well as the results of applied research directed at specific problems.

CONDUCT OF OCEANOGRAPHIC SCIENCE

In the past decade, oceanography has rapidly incorporated new technologies from other fields, remote sensing, material science, electronics, and computer science, for example. A fundamental change arising from the use of these new technologies is an increase in the quality and quantity of data collected and a dramatic increase in each oceanographer's capacity to study oceanic phenomena. As in many fields, the cost of making new discoveries in oceanography has escalated because these discoveries have been achievable only with the development and use of new satellites, vessels, laboratory and field instruments, and computers. This increased cost translates into an increased cost per scientist in the field, in what has been referred to as the "sophistication factor" by the President's Science Advisor, Dr. D. Allan Bromley. Yet, when adjusted for inflation, total research funding for ocean science has remained nearly constant over the past decade. During this interval, the number of Ph.D.-level academic oceanographers has increased by half again. The increase in the scientific capacity of each investigator and in the total number of qualified investigators, coupled with nearly constant overall federal funding, has resulted in inadequate support for many capable researchers.

Another significant change in the past decade is the onset of large-scale, long-term global research programs. Primarily planned and begun with NSF support, these programs focus the work of many scientists on global questions. These large programs are usually managed through national or international consortia that involve many scientists, multiple agencies, and often a number of countries. Such programs will explore new questions and test new mechanisms for working together in the next decade. Uncertainties about the changing environment of the planet are rapidly moving much of oceanography from a focus on projects that use the capabilities and interests of a single investigator for a limited time to projects that require the involvement of many individuals, institutions, and governments for decades. Special attention should be given to integrating mission agencies into the planning and execution of these long-term programs. Mechanisms must be developed to coordinate the plans of foreign nations, federal agencies, academic institutions, and individual scientists, and to sustain these large-scale efforts in a scientifically and technically sound manner.

The realization that global-scale studies are now not only possible but necessary is a major impetus for new partnerships in oceanography. Indeed, the design and deployment of a long-term global ocean observing system, now being planned, will be possible only if such partnerships are realized and the cooperation of marine scientists and governments throughout the world is achieved.

TOWARD NEW PARTNERSHIPS

Traditional partnerships in the ocean sciences have consisted primarily of academic scientists submitting proposals to the National Science Foundation and the Office of Naval Research for funding. This funding system is powerful and flexible, allowing the NSF and ONR to fund excellent scientists whose areas of expertise are those necessary to solve problems at the forefront of oceanography. Through their support of research and related infrastructure, these two agencies sustain the basic research programs at academic oceanographic laboratories. If significant progress in our basic understanding of the ocean is to continue, the excellent relationships of NSF and ONR with the academic community must be maintained. Agencies that fund oceanography can help maintain competence in the field as problem areas change. Flexibility and variety in scientific approaches can be maintained by an extramural funding strategy that both responds to changing problems and needs, and maintains a strong overall base of scientific activities in the field as a whole. It is more difficult for agencies to respond quickly to change through their own laboratories.

Many other federal agencies are also involved in marine science and policy, but their use of the marine science knowledge and their responsibility to the academic community vary widely. Agency responsibilities range from NSF's and ONR's active promotion of the health of basic science to the highly specific and practical rule-making procedures of the Environmental Protection Agency. The National Oceanic and Atmospheric Administration has a wide range of responsibilities in the ocean but is only now beginning to develop significant research programs in many of its areas of responsibility. The future vitality of basic oceanographic research in academia may depend on its forging productive partnerships with NOAA. Partnerships between academic oceanographers and NASA, DOE, USGS, or the Minerals Management Service will add diversity and vitality to the national oceanographic effort.

No simple description can usefully encompass the range of partnerships between federal agencies and the academic oceanography community. However, under the traditional arrangement, mission agencies, such as EPA, have received relatively little intellectual input from academia and provided relatively little funding to academic institutions. These agencies, whose short-term missions often require highly applied research, rely primarily on their own scientists. Yet, these same agencies have relied on academic scientists to provide the underpinning knowledge upon which their policy decisions are based. In general, the mission agencies have not contributed much to advancing fundamental knowledge in their areas of concern, perhaps assuming that NSF or ONR would fund basic research adequately. Such a perspective has the danger of focusing oceanography primarily on short-term applied problems. Achieving a sensible balance between basic and applied oceanographic research should be the concern of each agency using the results of ocean research.

As the context in which oceanography is conducted changes, how can federal agencies and oceanographers in academic institutions strengthen and improve their cooperative efforts? In general, partnerships must be extended beyond financial relationships to include the sharing of intellect, experience, data, instrument development, facilities, and labor.

Communication

Many mission agencies and academic scientists have little experience in interacting with one another, but both groups would benefit from doing so. **The board recommends that each agency with an ocean mission and without existing strong links to the nongovernment community establish permanent mechanisms for ensuring outside scientific advice, review, and interaction.** The obvious advantage of external consultation is that it provides an objective evaluation of agency needs and poses possible solutions from a new perspective. The National Research Council is but one possible source of external advice. **These advisory groups should report to a level sufficiently high that their views are presented directly to agency policy makers and the relationships are eventually institutionalized to establish a collective memory.**

The board recognizes that the existence of multiple marine agencies with differing mandates brings a vigor and diversity to the field. However, the lack of coordination and cooperation among agencies that conduct or sponsor marine research detracts from this advantage. Informal attempts at coordination have been largely unsuccessful; a formal mechanism is necessary. **The board recommends that, because no single agency is charged with and able to oversee the total national marine science agenda, an effective means be found for agencies to interact at the policy level and formulate action plans.**

One model for such interaction is the Committee on Earth and Environmental Sciences of the Federal Coordinating Council for Science, Engineering, and Technology. Regardless of the coordinating mechanism chosen, it must permit the agencies to develop a synergistic approach to addressing national problems and to coordinating programs and infrastructure. High-priority tasks for such a group would be an examination of the balance between individual investigator awards and large project support, and the establishment of guidelines for the large, global change projects.

Agency Responsibility for Basic Science

The vitality of basic ocean research in the United States resides principally in its academic institutions. **The board recommends that federal agencies with marine-related missions find mechanisms to guarantee the continuing vitality of the underlying basic science on which they depend.** In some agencies, the best mechanism is direct funding of individual investigator grants; in others, consultation and collaboration work well. NSF and, secondarily, ONR should retain primary responsibility for the vitality of the basic science, with NOAA becoming increasingly involved. Also, mission agencies such as EPA and DOE must share more fully in this responsibility. It is particularly important to encourage involvement of mission agencies in sampling and monitoring programs pertaining to long-term global change issues. At present, a disproportionate share of the funds is provided by NSF. As these programs expand, resources for individual investigator grants could be reduced if other agencies do not assume responsibility for some of the funding.

Responsibility of Academic Institutions

Through the years, academic oceanographic institutions evolved different organizational structures ranging from typical academic departments to large comprehensive institutions that operate multiple ships and shared facilities. As the benefits of cooperation became evident, vehicles for the cooperative use of ships and some other facilities have developed. **The board recommends that academic oceanographic institutions find additional ways to achieve cohesiveness among these institutions and a sense of common scientific direction.** It is essential that this cooperation be achieved at both the administrative and the working-scientist levels so that the interactions are based on the needs of science as well as the needs of the institutions. **The board also recommends that the academic institutions, individually or through consortia, take a greater responsibility for the health of the field, including nationally important programs.** In particular, the large, long-lived global change research programs are indicative of the need for institutional responses that are of longer duration and more stable than those of individual scientists. Also, the heavy dependence of academic oceanographers on federal support, compared with other fields, suggests that the academic institutions should explore mechanisms for the stable support of academic researchers. Academic scientists have a responsibility to help the federal agencies that fund them when it comes to applying research results to agency missions. Partnerships imply shared responsibilities and anticipation of the future needs of both partners.

Sharing of Academic and Federal Resources

The board recommends that federal and academic researchers improve the sharing of data, the cooperative use of facilities, and the conduct of joint research. Some mission agencies encourage cooperation with academic scientists, but increased formal interaction could significantly improve the efficiency of the national oceanographic effort. The major facility available to the marine science community, the research fleet, is a national resource. Maintaining, developing, and operating the fleet in the most efficient and cost-effective manner should be paramount in all discussions of shared resources.

Development of Instrumentation

Some advancement of oceanographic knowledge has come through the development of new observational technologies. Effective operational systems to solve the complex problems facing mission agencies will consist largely of instruments that either do not now exist or have not yet been redesigned for oceanography. The development of both in situ and satellite oceanographic instrumentation requires a long-term investment in novel technologies and in the extensive field trials necessary to make instruments operational. **The board recommends that to ensure continued progress in instrumentation, new mechanisms be found to address the long time frames necessary for instrument development in oceanography.** Mission agencies, whose success will depend increasingly on instrumentation that does not yet exist, should initiate suitable roles in the development of new technology.

Transfer of Responsibility

The division of tasks between academic scientists and agencies will depend on the agencies' missions, resources, and internal capabilities vis-à-vis the academic community's. Mechanisms must be developed to provide smooth transition from research activities to operational measurements. In particular, the proposed global ocean observing system will necessitate unprecedented levels of monitoring. **The board recommends that academia and federal agencies work together to ensure that appropriate long-term measurements are extended beyond the work of any individual scientist or group of scientists and that the quality of such measurements is maintained.**

Data Management and Exchange

The board recommends that the present system for data management and exchange within and among the various elements of the marine science community be modernized to reflect the existence of distributed computing systems, national and international data networks, improved satellite data links, and on-line distribution of oceanographic data. Also, provision must be made for future access to existing data.

Specific Partnerships

These general recommendations form the basis for building new partnerships between federal and academic interests in ocean science. Of course, they do not apply to all agencies to the same degree. The full report discusses aspects of specific partnerships for federal agencies with significant ocean programs. The board believes that if these new partnerships are established and nurtured, the next decade of ocean science research will be characterized by a robust program of basic research and significant progress toward the solution of marine problems of importance to humankind.

1

Introduction

IMPORTANCE OF THE OCEAN TO SOCIETY

The ocean dominates Earth's surface and greatly affects our daily lives. It regulates Earth's climate, plays a critical role in the hydrological cycle, sustains a large portion of Earth's biodiversity, supplies food and mineral resources, constitutes an important medium of national defense, provides an inexpensive means of transportation, is the final destination of many waste products, is a major location of human recreation, and inspires our aesthetic nature.

Today's sense of urgency about ocean studies is precipitated by human impacts on oceanic systems and the need for a better understanding of the ocean's role in controlling global chemical, hydrological, and climate processes. The nation is faced with pressing marine research problems whose timely solution will require increased cooperation between federal agencies and academic scientists. Many of these problems arise from the need to accommodate multiple uses of the ocean and from the ever-increasing concentration of the U.S. population near its coasts. Oceanographic research is important to many of the nation's social concerns, including the following:

- *Global Change.* The ocean plays a predominant role in regulating both natural and human-induced changes in our planet. The role of ocean circulation and the coupling of the ocean and the atmosphere are basic to understanding Earth's changing climate. Regional events such as El Niño and ocean margin and equatorial upwelling influence climate on both seasonal and longer time scales. The world's population is now large enough to alter the chemical composition of the ocean and atmosphere and to impact the biological composition of Earth.

- *Biodiversity.* The oceans comprise a large portion of Earth's biosphere and support a vast diversity of flora and fauna that are critical to Earth's biogeochemical cycles and serve as an important source of food and pharmaceuticals. In addition to the exciting discoveries of previously unknown biota near hydrothermal vents, many deep-ocean organisms have evolved under relatively stable conditions. Their unique physiologies and biochemistries have not yet been explored adequately, and methods for sampling the more fragile of these species have been developed only in the past decade. Human influence on marine biota has increased dramatically, threatening the stability of coastal ecosystems. Some species have been overharvested; others have been transported inadvertently to areas where they are not indigenous, sometimes resulting in deleterious effects on native species. Still other species are being cultivated commercially, and aquaculture facilities along coastlines are becoming commonplace in some countries. A better understanding of the ecology of marine organisms is urgently needed to prevent irreversible damage to this living resource.
- *Environmental Quality.* Waste disposed in coastal areas has reached the open ocean, with broad ramifications for living resources. This problem is compounded because many marine species harvested for commercial and recreational purposes spend a portion of their lives in coastal waters and estuaries. Thus, local pollution can have far-reaching effects.
- *Economic Competitiveness.* Economic prosperity in a global marketplace depends increasingly on technical and scientific applications. There is concern about the ability of the United States to compete with Europe and Asia. Basic and applied research in marine science and engineering is necessary to achieve and maintain a competitive position in a host of fields, including marine biotechnology, aquaculture, hydrocarbon and mineral exploration and production, maritime transportation, fisheries, treatment and disposal of waste, and freshwater extraction.
- *National Security.* Unprecedented world political changes are redefining national defense interests and altering research and development priorities. Knowledge of the ocean, especially the

acoustic properties of marginal seas and coastal areas, is critical to national defense. Experience gained in 1991 during the war in the Persian Gulf highlights the need for better information related to oceanic and coastal processes and to maritime operations and transportation.

- *Energy.* The ocean's energy resources are essential to the national economy and national security. After a decade of relative neglect, energy issues are reemerging. With oil supplies continually threatened by instability in the Middle East and with increasing atmospheric carbon dioxide viewed as a possible trigger of global warming, there is a need to look carefully at a full range of energy sources, from oil and gas in our Exclusive Economic Zone to wave and tidal power and ocean thermal energy conversion. Better knowledge of the ocean and seabed is necessary to exploit responsibly the ocean's untapped petroleum and natural gas resources.
- *Coastal Hazards.* This nation must improve its prediction of and response to coastal hazards, both natural and human induced. Hurricanes Hugo and Andrew, two of the strongest hurricanes of the century, devastated parts of the U.S. East Coast. Their impact reinforced the need for better predictive capabilities and a better understanding of coastal storm surges, flooding, erosion, and winds. The exploration for, and production of, petroleum and the transportation of petroleum and chemical products pose risks to the environment when spillage occurs. The movement, effects, and ultimate fates of spilled products must be understood for effective public response. The available information is woefully inadequate, particularly for fragile ecosystems such as coral reefs.

Increasing our knowledge about the ocean is a matter of urgency. Human-induced changes to the planet's oceans and atmosphere will increasingly affect the global cycles that ultimately control the number of people our planet can support. To predict the results of environmental disturbances and prescribe possible remedies, a better understanding of Earth's systems, including the ocean, must be acquired. For example, an important scientific and policy question today is whether Earth will warm in response to increasing concentrations of greenhouse gases in the atmosphere and, if so, how quickly. We know that the concentrations of these gases are increasing and that the most advanced climate models indicate that warming should occur. The ocean plays a key but poorly understood role in moderating both greenhouse gases and temperature change.

The coast of the United States is one of the nation's most valuable geographic features. It is at the junction of land and sea that most of the nation's trade and industry take place. The effectiveness with which the resources of the coastal zone are used is a matter of national importance. The multiple uses of valuable coastal areas generate intense state and local interest. From 1950 to 1984 the population in coastal counties grew more than 80 percent. By 1995, more than three-fourths of the U.S. population will live within 50 miles of the coastline.

Coastal waters and estuaries provide food and are the shelter and spawning grounds for almost two-thirds of the nation's commercial fish stocks. Oil, gas, and mineral resources in the coastal waters are essential to our national economy and security. Since the first offshore oil well was drilled off California in 1896, numerous oil and gas pools have been discovered near our coasts.

Recent reports of increased pollution of estuarine and coastal waters are cause for serious concern and action. Waste disposal, especially from pipelines, runoff, and dumping at sea, jeopardizes our ocean and coastal waters. The toll that waste takes on the ocean is persistent and growing. The continuing damage to estuarine and nearshore resources from pollution, development, and natural forces raises serious doubts about the survival of these systems. Better understanding of these systems is essential for good policy decisions.

Policy decisions concerning these and many other interactions of the ocean with everyday life rest upon a sound scientific understanding of the ocean. To the extent that such policy decisions are to be useful, they must be consistent with the best available information about how the system works: its physics, chemistry, geology, and biology. Both the government and the scientific community as a whole must ensure that what is known about the ocean is made available to policy makers, that what is not known is clearly stated, and that progress in furthering our basic understanding continues.

MAINTAINING EXCELLENCE

Our nation excels in oceanography. Since World War II, the United States has been a world leader in essentially every area of oceanography. To maintain this excellence will require a talented population of scientists, an informed and educated public, a society that is interested in and appreciative of new discoveries, open lines of communication between oceanographers and the scientific community at large, and economic resources for conducting oceanographic research on the frontiers of knowledge. Excellence in oceanography also requires harmony between its basic scientific aims and the pressing needs of society.

We cannot take for granted the continued excellence of oceanography in the United States because the foundation of facilities and human resources developed in the past must be renewed constantly. Continued excellence in oceanography is essential to the national interests of the United States. Agencies that fund oceanography can help maintain the competence of the field as problem areas change. Flexibility and variety in scientific approaches can be maintained by an extramural funding strategy that both responds to changing problems and needs and maintains a strong overall base of scientific activities in the field as a whole. It is more difficult for agencies to respond quickly to change through their own laboratories.

Vannevar Bush's *Science: The Endless Frontier* is still the classic statement of the essential ingredients of scientific excellence. He noted that "without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world. This essential new knowledge can only be obtained through basic scientific research.". He further stated that "basic research is performed without thought of practical ends . . . leads to new knowledge, provides scientific capital, creates the funds from which the practical applications of knowledge must be drawn." Finally, he stated that "government must fund science in accordance to certain fundamental principles" including the essentiality of quality, improved efficiency of research expenditures, and increased cooperation in setting goals and priorities.

U.S. OCEANOGRAPHY SINCE WORLD WAR II

In the aftermath of World War II, the United States constructed a scientific research mechanism of outstanding success, which for years dominated scientific progress. Many studies described the nature of this research enterprise. A wide consensus exists that much of its success has been due to the partnership between the federal agencies that became the patrons of science and technology and the major research universities, both public and private. Marine science shared in the general outstanding progress, although its history is exceptional in several ways.

The war thrust the United States into global affairs, and its many sea campaigns not only drew public interest to the ocean but also highlighted our ignorance of it. Most members of the small marine science community turned to military-oriented work in uniform, in the civil service, or at universities and related institutions. Academic ships, as well as those of the federal government, were put to work on Navy research and surveying tasks. The Navy needed and received oceanographic help in everything from submarine warfare to amphibious landings. Although this assistance contributed to the war effort, of even more importance, it impressed on the nation the fact that marine science was not an abstract endeavor but could contribute to the public good in many fields.

The plan of Vannevar Bush at the end of World War II for government support of university science led to the formation of the Office of Naval Research (ONR). It was charged with ensuring the development of strong academic research programs in scientific fields of interest to the Navy. The growing Cold War and the threat from both surface and, particularly, submarine vessels led ONR to conclude that expanding and generally strengthening the basic science of the ocean were in the national interest. With ONR's financial backing, existing marine research centers were expanded and new ones created. Initially, ONR was more concerned with institutional support than with program definition. There was generally only one contract per institution, proposals of work were often loosely defined, and the director of the institution had considerable discretion in transferring funds from one investigator to another. In 1950, the National Science Foundation (NSF), dedicated primarily to the support of peer-reviewed single-investigator research in the academic community, was created.

The postwar and post-*Sputnik* periods from 1960 to 1980 were marked by a national awareness of the rest of the world and an intense interest in science. These encouraged international cooperation in research, tempered strongly by a U.S. desire to achieve world leadership in science and technology. In marine science, interest grew from our coastlines to the globe, leading to such major ocean-related programs as the International Geophysical Year, the Deep Sea Drilling Project, and the International Decade of Ocean Exploration. Through both its small science programs and large coordinated programs, NSF rapidly became a significant supporter of oceanography and is now the dominant supporter of academic ocean research. The Navy, which almost single handedly provided impetus and financial support for the postwar academic expansion in oceanography, has progressively concentrated its support in a relatively limited number of Navy-relevant areas and in providing major oceanographic research vessels. NSF has increasingly borne the costs of both research and ship operations.

The National Oceanic and Atmospheric Administration (NOAA), established in 1970, has developed several mechanisms for working with the academic community. NOAA's National Sea Grant College Program added a new dimension to university marine science programs by concentrating primarily on applied coastal research and developing extension and public information networks. In particular, Sea Grant supported areas of marine science not emphasized by ONR and NSF—the study of estuaries, fisheries, and pollution and the transition of such research to practical applications. The proximity of NOAA oceanographic and fisheries laboratories to academic institutions leads to opportunities for joint educational and research programs, of benefit to both the academic and the federal laboratories. NOAA provides comparatively modest extramural research funds as part of its Climate and Global Change Program and its Coastal Ocean Program and through the National Marine Fisheries Service. Other federal agencies support academic scientists, notably the Departments of Interior and Energy, the Environmental Protection Agency, and the National Aeronautics and Space Administration.

In the past decade, oceanography has incorporated new technologies from other fields, for example, space research, electronics, and computer science. A fundamental change arising from the use of new technologies has been an increase in both the quality and the quantity of data collected. Thus each oceanographer's capacity to study ocean phenomena has increased dramatically. This increase has also increased the cost of each oceanographer's scientific research.

Another significant change is the planning, primarily with NSF support, of large-scale, long-term global research programs that focus the work of many scientists on global ocean questions. These large programs are part of the overall scientific quest. They are usually managed by international consortia that involve many scientists, multiple agencies, and often a number of countries. The experience of working in these programs will lead us to ask different questions and to explore different mechanisms of working together in the next decade.

U.S. STYLE OF LARGE PROGRAM MANAGEMENT

Since the 1970s, U.S. marine scientists and the federal government have shown remarkable ingenuity in developing mechanisms to meet the challenges of large new programs. Instead of developing large permanent organizations with new facilities as in some other countries, U.S. programs, such as the Mid-Ocean Dynamics Experiment, Geochemical Ocean Sections, Coastal Upwelling Ecosystem Analysis, and the Climate: Long-Range Investigation, Mapping, and Prediction projects, have evolved differently. Large programs typically developed within the academic community through workshops. The community formed scientific steering groups, which were accepted and funded by NSF and other federal agencies, and set up program offices. These offices are located at academic institutions, and program staff is hired for the project duration. The program office may move as the leadership of the program changes. Upon completion of the research program, the staff assumes other duties and the facilities are used for other purposes, so there is no long-term drain on agency resources.

OCEANOGRAPHIC RESEARCH, NATIONAL AND INTERNATIONAL

Oceanographic research involves studies of the motion of the water, the distribution of marine life, and the interaction of seawater with ocean boundaries. Knowledge of the exchanges of energy, heat, and mass at the ocean-atmosphere interface is important to climate and weather prediction. Oceanographic research has advanced from the past era of exploration to one of observation and description of ocean systems and of processes within the ocean and among the ocean, atmosphere, and ocean basins and boundaries. Because of the advances in satellite observation, computer modeling, and technology (e.g., global positioning systems and acoustic tomography), the coming decade of research holds much promise.

The ocean science community has developed several multi-institutional, interdisciplinary research programs that should significantly improve our knowledge of physical, chemical, geological, and biological processes occurring in the ocean. One important goal of these programs is to understand ocean processes in sufficient detail to allow predictions to be made of the impact of human activities on the environment. Because of the global scale of many environmental problems and the substantial resources (i.e., financial, infrastructure, and human) required, large ocean research programs are often cooperative international efforts.

The nation's academic capability in ocean science is robust. It is reflected in strong academic departments at many public and private universities, mixed with a few large oceanographic centers. U.S. academic oceanographers are internationally recognized leaders who are key to international scientific activity. Although the United States funds perhaps half of the global total of oceanographic research in many of its disciplines, international cooperation is vital for achievement of the goals of most large global research programs. The academic community could contribute significantly to the study of the ocean and to solutions to the spectrum of ocean-related environmental problems now facing the nation and the world.

THIS REPORT

Objectives

This report has three major objectives. The first is to document and discuss important trends in the human, physical, and fiscal resources available to oceanographers, especially academic oceanographers, over the last decade. Its second goal is to present the board's best assessment of the scientific opportunities in physical oceanography, marine geochemistry, marine geology and geophysics, biological oceanography, and coastal oceanography during the upcoming decade. The third and principal objective is to provide a blueprint for more productive partnerships between academic oceanographers and federal agencies. The board attempts to do this by developing a set of general principles that should provide the basis for building improved partnerships and by discussing critical aspects of the specific partnerships for each federal agency with a significant marine program.

Contents

Chapter 1 introduces the importance of the ocean to society and the need for maintaining excellence in marine-related research and education. The growth of U.S. academic oceanography since World War II and the structure of both national and international research are discussed.

Chapter 2 discusses partnerships in ocean science. A general partnership theme is presented, followed by specific partnership possibilities with agencies of the federal government. This report does not discuss partnerships with states and industry, which may be explored by the board at a later time.

Chapter 3 details some of the scientific opportunities of the next decade and some of the most important ongoing research programs. It describes opportunities and programs for each of the four major subdisciplines of oceanography: physical, chemical, geological, and biological, as well as for the interdisciplinary area of coastal oceanography.

Chapter 4 presents information about the infrastructure of oceanography. Included is a discussion of the human, physical, and fiscal resources. This initial overview of the field's resources raises many questions that should be examined at a later date. In-depth analysis and synthesis remain to be carried out.

2

Toward New Partnerships in Ocean Sciences

Since about 1950, scientific research in the United States has been characterized by federal funding of academic scientists to conduct research of general interest to the government. This defines a partnership of sorts, a mutually beneficial relationship between the federal government and academic scientists. In ocean science to date, these traditional partnerships have consisted primarily of scientists in academic and private institutions submitting proposals to the National Science Foundation (NSF) and the Office of Naval Research (ONR). This funding system is powerful and flexible, allowing NSF and ONR to fund excellent scientists whose areas of expertise are those necessary to solve problems at the forefront of oceanography. The two agencies encourage and sustain basic research programs at academic and private laboratories. The numerous federal agencies involved in marine science and policy differ greatly in their use of marine science knowledge and in their responsibility to the academic community. Agency responsibilities range from NSF's and ONR's active promotion of the health of basic science to highly specific and practical rule-making procedures of the Environmental Protection Agency (EPA). The National Oceanic and Atmospheric Administration (NOAA) has a wide range of responsibilities in ocean matters but is just beginning to develop significant research programs in many of its areas of responsibility. The future vitality of basic oceanographic research within academia may depend on its forging productive partnerships with NOAA. No simple description can usefully encompass the range of partnerships between federal agencies and the academic oceanography community. However, under the traditional arrangement, mission agencies (e.g., EPA) received relatively little direct intellectual input from academic and private scientists, and provided relatively little funding to academic institutions. Yet, although such agencies have relied on academic scientists for much of the basic knowledge required to understand policy questions, they have not assumed a serious responsibility to advance that knowledge. These agencies, whose short-term missions often require applied research, rely primarily on agency scientists to carry out their missions with optimal short-term efficiency.

The traditional scientific partnerships that have existed over the past 40 years are likely to change because the focus of oceanography and the way it is carried out are changing. Increased emphasis on the global scale and on multidisciplinary research, the changing emphasis of naval oceanography, and increasingly limited resources relative to an expanded capacity to conduct science by using modern instrumentation and computing are all contributing to change. These factors are pushing the field of oceanography toward serious consideration of the greater efficiency that could be achieved by a better coordinated national oceanography effort.

Our nation is faced with many pressing problems whose solutions would benefit from increased cooperation between federal agencies and nongovernmental scientists. Ocean research programs that developed from scientists' curiosity about nature have a new social context and urgency. A salient example is global change in all its aspects, including ocean circulation, air-sea transfer of gases, response of organisms, sea-level rise, and other effects of a potentially warming Earth. A balance should be maintained between the complementary approaches of large programs and individual investigator science in order to preserve the diversity and vigor of the field. Individual investigator science can be a fertile source of innovative ideas, whereas large programs can garner the resources for global-scale studies and can add momentum, collective wisdom, and resources for long-range planning.

A major impetus for new partnerships in oceanography is the realization that a global scale of study is now both possible and desirable. The design and deployment of a global ocean observing system, now being discussed, will be possible only with cooperation among the world's ocean scientists and its governments. Such a system will be necessary for obtaining enough long time-series global data to understand the global climate system and predict its response to human influence.

Oceanography is changing rapidly from its focus on the capabilities and interests of single or small groups of investigators involved in studies of limited duration to a focus on scientific questions of global scope, involving large numbers of individuals, institutions, and governments; spanning decades; and having major significance to society. The role of the individual investigator in this context has not lessened. Mechanisms must be developed by which these new large-scale efforts are sustained in a scientifically and technically sound manner and the plans of a variety of federal agencies and nations are coordinated.

A major reason for the preeminence of U.S. marine science is the great diversity of institutions in the field. This diversity is a key to future strength and it needs to be maintained. This statement does not suggest, however, that the present numbers and types of institutions are necessarily optimal for the future.

GENERAL PARTNERSHIP THEMES

The health of the marine sciences in the United States must be maintained because of the continuous need for fundamental knowledge as the basis for developing sound public policy. The health of ocean science depends on a complex symbiosis that must be constantly nurtured. The academic and private oceanographic institutions, working with the federal government, have shown remarkable ingenuity in developing mechanisms to coordinate multi-institutional resources (e.g., the University-National Oceanographic Laboratory System (UNOLS) and the Joint Oceanographic Institutions, Inc. (JOI)). UNOLS is a multi-institution system for coordinating scheduling, safety, refitting, and replacement of academic oceanographic vessels. JOI, governed by representatives of 10 of the largest oceanographic institutions, was founded initially to manage the Deep Sea Drilling Project; JOI now undertakes broader responsibilities for large programs and new technology. In addition, several research programs (e.g., the Tropical Ocean-Global Atmosphere program, Mid-Ocean Dynamics Experiment, Geochemical Ocean Sections, and Coastal Upwelling Ecosystem Analysis) successfully combined the efforts of U.S. government agencies, agencies of other countries, and federal and nongovernmental scientists, both domestically and internationally.

As the context in which oceanography is conducted changes, how can partnerships between federal agencies and oceanographers in academic and private institutions be strengthened and improved? In general, the partnerships must extend beyond financial relationships to include the sharing of intellect, data, instrument development, facilities, and labor. Key elements in such partnerships are encouraging individual scientists to take intellectual risks in advancing basic knowledge, providing support that is tied to solving existing problems, and encouraging scientists to cooperate in the development of large shared research endeavors.

Communication

Many mission agencies and academic scientists have little experience interacting with one another, but both groups would benefit from doing so. **The board recommends that each agency with an ocean mission and without existing strong links to the nongovernment community establish permanent mechanisms for ensuring outside scientific advice, review, and interaction.** The obvious advantage of external consultation is that it provides an objective evaluation of agency needs and poses possible solutions from a new perspective. The National Research Council (NRC) is but one possible source of external advice. **These advisory groups should report to a level sufficiently high that their views are presented directly to agency policy makers and the relationships are eventually institutionalized to establish a collective memory.**

The board recognizes that the existence of multiple marine agencies with differing mandates brings a vigor and diversity to the field. However, the lack of coordination and cooperation among agencies that conduct or sponsor marine research detracts from this advantage. Informal attempts at coordination have been largely unsuccessful; a formal mechanism is necessary. **The board recommends that, because no single agency is charged with and able to oversee the total national marine science agenda, an effective means be found for the agencies to interact at the policy level and formulate action plans.**

One model for such interaction is the Committee on Earth and Environmental Sciences of the Federal Coordinating Council for Science, Engineering, and Technology. Regardless of the coordinating mechanism chosen, it must permit the agencies to develop a synergistic approach to addressing national problems and to coordinating programs and infrastructure. High-priority tasks for such a group would be examination of the appropriate balance between individual investigator awards and large project support and the establishment of guidelines for the large, global change projects.

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Through the years, academic oceanographic institutions evolved different organizational structures ranging from typical academic departments to large comprehensive institutions that operate multiple ships and shared facilities. As the benefits of cooperation became evident, arrangements for the cooperative use of ships and some other facilities have developed. **The board recommends that academic oceanographic institutions find additional ways to achieve cohesiveness among the institutions and a sense of common scientific direction.** It is essential that this cooperation be achieved at both the administrative and the working-scientist levels so that the interactions are based on the needs of science as well as the needs of the institutions. **The board also recommends that academic institutions, individually or through consortia, take a greater responsibility for the health of the field, including nationally important programs.** In particular, the large, long-lived global change programs could benefit from institutional responses that are of longer duration and more stable than those of individual scientists. Also, the heavy dependence of academic oceanographers on federal support, compared with other fields, suggests that academic institutions should explore mechanisms for the stable support of their researchers. Academic scientists have a responsibility to help the federal agencies that fund them when it comes to applying research results to agency missions. Partnerships imply shared responsibilities and anticipation of the future needs of both partners.

Sharing of Academic and Federal Resources

The board recommends that federal and academic researchers improve the sharing of data, the cooperative use of facilities, and the conduct of joint research. Some mission agencies encourage cooperation with academic scientists, but increased formal interaction could significantly improve the efficiency of the national oceanographic effort. The major facility available to the marine science community, the research fleet, is a national resource. Maintaining, developing, and operating the fleet in the most efficient and cost-effective manner should be paramount in all discussions of shared resources.

Development of Instrumentation

Some advancement of oceanographic knowledge has come through the development of new observational technologies. Effective operational systems to solve the complex problems facing mission agencies will consist largely of instruments that either do not now exist or have not yet been redesigned for oceanography. The development of both in situ and satellite oceanographic instrumentation requires a long-term investment in novel technologies and in the extensive field trials necessary to make instruments operational. **The board recommends that to ensure continued progress in instrumentation, new mechanisms be found to address the long time frames necessary for instrument development in oceanography.** Mission agencies, whose future success will depend increasingly on instrumentation that does not yet exist, should initiate suitable roles in the development of new technology.

Transfer of Responsibility

The division of tasks between academic scientists and agencies will depend on the agencies' missions, resources, and internal capabilities vis-à-vis the academic community's. Mechanisms must be developed to provide smooth transition from research activities to operational measurements. In particular, the proposed global ocean observation system will necessitate unprecedented levels of monitoring. **The board recommends that academia and federal agencies work together to ensure that appropriate long-term measurements are extended beyond the work of any individual scientist or group of scientists and that the quality of such measurements is maintained.**

Data Management and Exchange

The board recommends that the present system for data management and exchange within and among the various elements of the marine science community be modernized to reflect the existence of distributed computing systems, national and international data networks, improved satellite data links, and on-line distribution of oceanographic data. Also, provision must be made for future access to existing data.

SPECIFIC PARTNERSHIPS

These general recommendations form the basis for building new partnerships between federal and academic interests in ocean science. Of course, they do not apply to all agencies to the same degree. This section discusses aspects of specific partnerships of the academic oceanography community with each federal agency having a significant ocean program.

Oceanography is now supported by a number of federal agencies using a variety of mechanisms. Federal-academic arrangements differ; the paternal care by the early ONR immediately after World War II, the creation of NSF to foster basic research, the mandated joint fiscal partnership of the National Sea Grant College Program, and cooperative agreements between academic institutions and federal laboratories are salient examples. This section explores aspects of establishing new partnerships between academia and several federal agencies: NSF, the Navy, NOAA, EPA, the Minerals Management Service (MMS), the National Aeronautics and Space Administration (NASA), DOE, and the U.S. Geological Survey (USGS). The discussions are not meant to be inclusive. Further, these discussions are sketches of issues and possibilities, not definitive blueprints. The design of new partnerships and their sustenance must be a fully collaborative process between agency representatives and marine scientists in academic institutions. Some collaboration has already occurred; other cooperative arrangements need to be developed.

Partnerships between the academic community and the agencies that fund ocean research can be improved in several ways. One major improvement would be for the academic institutions to make it career enhancing and attractive for scientists to serve as short-term scientific officers (rotators) at federal agencies. There is a perennial shortage of rotators at these agencies. Rotators should be respected among their peers within the academic community, and assignments should be chosen carefully to benefit both the government and the scientist. Also, scientists should be rewarded for service on federal advisory panels and on community-wide management groups such as the committees of the Ocean Drilling Program.

National Science Foundation

The National Science Foundation was formed in 1950 to increase the nation's base of scientific and engineering knowledge and to strengthen its ability in research and education in all areas of science and engineering. NSF supports fundamental, long-term, merit-selected research in all the scientific and engineering disciplines, including oceanography. NSF maintains strong relationships with academic scientists and is the major source of funding for basic ocean research.

NSF depends heavily on external scientists for program management, program review, individual peer review of proposals, and review panel memberships. The Division of Ocean Sciences (OCE) is the primary supporter of ocean science research within NSF, with specific programs for physical oceanography, chemical oceanography, biological oceanography, marine geology and geophysics, ocean technology, the Ocean Drilling Program, and a program to support facilities for oceanography. Ocean science research is also supported by the Division of Polar Programs, Division of Atmospheric Sciences, Division of Earth Sciences, and Division of Environmental Biology.

OCE depends on its Advisory Committee on Ocean Sciences (ACOS), which prepares long-range plans for the Division of Ocean Sciences. These plans, prepared with input from the ocean science community, identify needs and priorities for ocean science research and research infrastructure. The past two plans were reviewed by the Ocean Studies Board (OSB). A new strategic plan for ocean sciences is being prepared by ACOS, and OSB is expected to be involved.

The Ocean Studies Board (in conjunction with the NRC Board on Earth Sciences and Resources) reviewed the Ocean Drilling Program Long-Range Plan. NSF also depends on outside groups for program and facility management. For example, the Ocean Drilling Program receives advice from the Joint Oceanographic Institutions for Deep Earth Sampling, an international consortium with advisory groups of scientists from the academic community.

The present partnership is basically healthy, and the continued vigor of marine science will depend more than ever on NSF leadership in maintaining the fundamental science. Numerous aspects of the partnership require constant attention: the need for NSF to broker interagency funding for basic science as its own resources are outstripped; the balance between organized scientific efforts and individual investigator, independent grants; and determination of the proper balance among disciplines.

Department of the Navy

The Office of Naval Research has enjoyed a healthy partnership with the academic oceanographic community since its inception. Specifically, ONR funded basic academic research and was largely responsible for the early development and maintenance of oceanography. The academic partnership with ONR has been intellectual as well as financial. ONR depends on external scientists to review its programs through site and program-level reviews and to help develop its science programs through topical workshops. ONR also receives academic advice on program opportunities from the Naval Studies Board and Marine Board of the NRC and the Navy Committee of the Ocean Studies Board. Additional academic input is gained from rotators who come to ONR from the academic community for a few years and then return to academia. ONR's support of academic ship operations has declined in the past few years, which has led to questions about its balance of field and theoretical programs. A joint ONR-academic study of this balance would be useful.

With the end of the Cold War, the focus of Navy-funded research is almost surely going to shift, along with the general level and direction of Defense Department funding. For example, it has been suggested that the recent war in the Persian Gulf implies a greater focus on nearshore problems. However, the Navy, along with NSF, has been the backbone of the U.S. commitment to basic ocean science with a long-term view. Any diminishing of that commitment can, in the long run, undermine both science and national security. The board notes, for example, that the Office of Naval Research is virtually the only federal agency supporting basic research in ocean acoustics.

The Navy recently completed a major consolidation of its laboratories. The result is one "corporate" laboratory, the Naval Research Laboratory (NRL), and four centers: the Naval Air Warfare Center, the Naval Surface Warfare Center, the Naval Undersea Warfare Center, and the Naval Command Control and Ocean Surveillance Center. These organizations, which primarily conduct research on weapon systems and sensors, provide limited general funding and program support to the academic research community. In addition, NRL has a strong continuing relationship with the applied physics laboratories of four universities: Johns Hopkins University, the University of Washington, Pennsylvania State University, and the University of Texas at Austin. As the nation faces budgetary constraints, it is likely that NRL and its centers will explore more cooperative activities with the academic research community, especially in light of the reduction in number of the Navy's dedicated oceanographic ships.

The Office of Naval Technology supports Navy laboratories, universities, and private corporations to carry out its mission in the Navy's Exploratory Development (6.2) program. The academic institutions refine and transfer basic research results into technical feasibility and demonstration plans.

The Oceanographer of the Navy, who serves on the staff of the Chief of Naval Operations, is primarily responsible for providing the oceanographic products and services needed by the Navy's operational forces. In terms of direct funding of research, the Office of the Oceanographer of the Navy and its supporting organizations have only a modest relationship with the academic research community. However, the oceanographer's office provides the oceanographic community with access to global data sets and modeling capability. Data available from the Navy's monitoring network could be an important component of a global ocean observing system. The Navy possesses classified data about the ocean that could benefit ocean science research without compromising national security. It is noteworthy that the Office of the Oceanographer of the Navy has worked over the past three years to declassify much of the data it possesses on seafloor and sea surface topography. Oceanographers look forward to receiving access to more of the data possessed by the Navy. Also, the

Oceanographer of the Navy sponsors all its new oceanographic ship construction, including Navy-owned research ships that are operated by academic institutions. As part of the modernization of the Navy's 1960-vintage oceanographic fleet, the Oceanographer of the Navy ordered three new ships (AGOR class) for the academic research community. The first of these 275-foot-long, multipurpose, deep-ocean-capable research ships (R/V *Thomas Thompson*) was delivered in 1991 to the University of Washington. One of the remaining two new ships will be operated by Scripps Institution of Oceanography and the other by Woods Hole Oceanographic Institution.

An important initiative begun by the Oceanographer of the Navy in 1990 was the sponsorship, in cooperation with the Chief of Naval Research and the OSB, of a tactical oceanography symposium to familiarize the academic community with the Navy's operational needs and requirements. This initiative has become an annual event, and the Office of Naval Technology joined as one of the sponsoring organizations in 1992. The Oceanographer of the Navy is striving to facilitate closer links between the operational side of the Navy and the research community.

National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration was formed in 1970 from a combination of existing government entities. Its mission is to explore, map, and chart the global ocean and its living resources and to manage, use, and conserve those resources; to describe, monitor, and predict conditions in the atmosphere, ocean, Sun, and space environment; to issue warnings against impending destructive natural events; to assess the consequences of inadvertent environmental modification over several scales of time; and to manage and disseminate long-term environmental information.

Several partnerships now exist between NOAA and the academic community. The National Sea Grant College Program provides support for the study of estuaries and coastal regions, marine applied research, and the application of research to practical problems. Sea Grant is different from most other government-funded research programs in that it is a mandated partnership. Every two dollars of federal funds must be matched by at least one dollar, often from state agencies. Because of this mandated fiscal partnership, policy makers at the state level are generally more aware of Sea Grant research than of research sponsored by other federal agencies. Sea Grant also provides public service through its marine extension and public information components. The partnership has been successful, but its prospects for growth are limited by budget constraints. Further interaction with the academic community will depend on whether the program can find new directions that will justify increased funding.

NOAA also has marine laboratories located near academic oceanographic institutions. The laboratories often support graduate students who carry out thesis research of direct interest to NOAA. Educational opportunities for federal employees range from formal degree programs to seminars and library facilities available at universities. There are also opportunities for cooperative research programs and several NOAA/university joint institutes have been developed. Cooperative agreements between academic and federal laboratories should be expanded to develop stronger intellectual ties between NOAA and the universities.

NOAA provides modest extramural research funds as part of its Climate and Global Change Program and its Coastal Ocean Program, and through the National Marine Fisheries Service. These programs are a good start, showing agency recognition of the need for a broad base of support. The extramural programs should be strengthened to lend stability and to develop close intellectual ties, which are essential if the research is to meet agency needs. Further, critical issues such as the transition of the global ocean observing system to an operational phase must be examined in the context of NOAA's overall responsibilities and of research results from the Climate and Global Change Program and the Coastal Ocean Program. Development and implementation of a global ocean observing system, led by NOAA, would require better partnerships among agencies and between NOAA and academic scientists.

NOAA and the academic community should together evaluate the effectiveness of NOAA research. This examination should include the existing NOAA/university joint institutes, environmental research laboratories, and extramural research support. Improving the quality of scientific research within NOAA, clarifying its role vis-à-vis external science and agency missions, and stabilizing support for extramural research over the long term are clearly in the national interest. A panel of outside experts should work with NOAA's administration to review alternative approaches for extramural and intramural support, including the merits of different funding mechanisms (e.g., the NSF peer-review model, the ONR omnibus contract model, and the existing NOAA cooperative institute model).

The present NOAA fleet consists of 23 ships, of which 5 are inactive and many are old compared to the UNOLS fleet. NOAA's fleet is used primarily to carry out its operational mission in mapping, charting, and fisheries assessment, as well as NOAA research. The fleet occasionally supports other federal and state agencies, academic institutions, and private industry through various arrangements. For several years, NOAA has experienced funding shortfalls for ship operations, resulting in unmet program requirements. NOAA will have to replace its aged fleet and/or use ships owned by others. Under a cooperative arrangement with the academic community, NOAA Corps officers operate the *Vickers*, owned by the University of Southern California. This experiment has not yet concluded and thus has not been evaluated. NOAA and the academic institutions should consider other mechanisms for cooperative ship use, including the use of academic ships by NOAA scientists.

Discussion of the future shape and use of NOAA research vessels should take place within the larger debate on how to manage, upgrade, and use the research vessels operated by all agencies. The concept of a national research fleet is providing a context for this discussion. It is clear that we can no longer afford the luxury of regarding individual agency vessels as unrelated, with no sharing of resources.

A major obstacle for marine science lies in the difficulties of developing and managing spaceborne instruments over the next decades. Historically, NASA developed meteorological spacecraft that eventually evolved into operational systems managed by NOAA. However, for marine observations, apart from long-standing efforts in visible and infrared sea surface temperature observations and microwave sea ice measurements (both of interest to short-term forecasting), there is no effective mechanism for the systematic development or transfer of technology from research to operations. Some mechanism must be found to routinely collect such observations that are important to the NOAA mission. NOAA will need additional funding to carry out these observations, and a partnership arrangement will be necessary to identify the essential variables to be observed.

Another area of potential partnerships involves data bases, especially their accessibility. NOAA is responsible for the National Oceanographic Data Center (NODC). Created in the 1950s, NODC is intended to provide both present access to data and an archive for future generations. However, the center has failed to keep abreast of changing technologies in observation and data base management. As global programs generate increasing volumes of data and place new demands for the use of data from all sources, the need for modern national data facilities will become increasingly urgent. Because working scientists are often the source of many of the data and are often the largest potential users, they should participate in the design and use of these important data bases. The Joint Environmental Data Analysis center at Scripps Institution of Oceanography, which involves active scientists in the quality control and decisions of archiving data, is a first step in developing such partnerships.

Environmental Protection Agency

Since its founding in 1970, the Environmental Protection Agency has developed numerous regulations relative to both air and water, and environmental quality in many previously heavily polluted areas has improved as a result of these controls. Now, as environmental problems on regional, national, and international scales are increasingly recognized, EPA's challenge is to improve our understanding and management of the sources of pollutants and the environments that receive waste. The EPA Science Advisory Board (1990), in its landmark report *Reducing Risk*, stated that too little attention is paid to environmental problems that have significant large-scale consequences and low reversibility (e.g., global climate change and loss of habitats and biodiversity). In the past, EPA has relied on internal expertise for scientific input, but the range of problems and their complexity can no longer be handled in this way. EPA has made a commitment to the increasing use of scientific advice throughout its activities. Meeting this commitment will require strong partnerships with the academic community.

EPA's need both to view pollution control from a larger environmental perspective and to increase its reliance on science offers prospects for partnerships with the academic ocean science community. EPA engages scientists in its environmental research laboratories, a relatively small extramural grants program, exploratory environmental research centers, and environmental management programs, including the National Estuary Program. An expanded EPA partnership with the academic community could include the following:

- expansion of the extramural grants program and creation of additional environmental research centers collocated with universities and specifically focused on present and future problems in the marine environment;

- agreements between EPA research laboratories and nearby academic or private institutions;
- training of EPA personnel in newly emerging science that enhances the science perspective in order to balance the strong regulatory perspective that exists within the agency; and
- increased reliance on academic experts in areas in which they may be better positioned than commercial consultants (e.g., analysis of long-term and large-scale environmental problems).

Problems with the agency's approach to academic grants and centers have discouraged many university-based experts from working with EPA. In addition, the program and regional offices and the Office of Research and Development laboratories often rely on contractual mechanisms that prevent EPA from obtaining the best outside scientists to work on agency issues. EPA should move quickly to bolster its grants and centers programs. The agency should also implement a long-term plan to replace contractual mechanisms that may be detrimental to obtaining the best possible scientific information.

Minerals Management Service

In 1973, in response to the threat of an international oil embargo, President Nixon announced an ambitious program for accelerated exploration and development of the oil and gas resources of the outer continental shelf (OCS) of most of the United States. Although it had managed offshore development in the northwestern Gulf of Mexico for many years, the Bureau of Land Management (BLM) was suddenly required to evaluate the environmental consequences of greatly expanded exploration and development. Since that time, through the BLM (now MMS) Environmental Studies Program, the Department of the Interior has spent more than $259 million for studies of the climate, circulation, contaminant levels, ecology, living resources, geohazards, and effects of oil and gas development in all OCS areas, particularly those with no previous development.

Although many academic ocean scientists have been involved in MMS studies, the agency has traditionally relied on commercial procurement contracting to acquire technical information. Some consequences of this approach are that relatively little of the information produced was published in the open scientific literature, whereby it could undergo peer review and perhaps gain broad credibility, and a cadre of environmental scientists, who could influence public opinion and policy, was not nurtured. Further, the program's emphasis on short-term results as opposed to long-term understanding provided limited opportunity for research innovation. To overcome these limitations, MMS has sought to increase the involvement of academic ocean scientists in its Environmental Studies Program through a variety of mechanisms: (1) two cooperative agreements with university groups to support investigator-initiated research on the long-term effects of petroleum development activities (i.e., the Louisiana Universities Marine Consortium in the Gulf of Mexico and the University of California-Santa Barbara in southern California); (2) other cooperative agreements with academic institutions that have unique capabilities for meeting MMS information needs; (3) the award of competitive contracts for large projects to academic institutions (e.g., Louisiana-Texas shelf physical oceanography studies at Texas A&M's Texas Institute of Oceanography and Louisiana State University); (4) extensive involvement of academic oceanographers on the scientific committee of the OCS advisory board and on quality review boards of various studies; and (5) increased emphasis on publication of study results in the open scientific literature.

MMS is already actively seeking to develop partnerships with academic oceanography, but to further these relationships, it should consider the following:

- expansion of the cooperative agreements for strategic investigator-initiated research on long-term environmental and socioeconomic effects of oil and gas in developed OCS regions;
- use of academic institutions (similar to the recently initiated physical oceanographic studies in the Gulf of Mexico and off California) for complex scientific studies that require the innovation and integration for which these institutions are particularly well qualified; and
- participation in the shared use of the academic research fleet with other federal agencies through more active involvement with UNOLS. MMS research vessel requirements and scheduling constraints do not always coincide with the availability of UNOLS vessels.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration develops new technology for space, demonstrates its use for a variety of scientific and technical purposes, and supports related science. NASA-developed technology provided the first synoptic views of Earth, and NASA Earth observation programs have since evolved into the present international operational and research missions for remote sensing of processes in the atmosphere and at the ocean and land surfaces. The great difficulty in observing the ocean by conventional means (ships and buoys) led oceanographers early in the post-*Sputnik* period to recognize the value of spaceborne observations.

In the more than 30 years since satellite imagery was first demonstrated, NASA and the ocean community have achieved notable successes. Satellite-measured sea surface temperatures are now routine input for weather and climate forecasting. NASA guided this technology to its present mature operational state. The *Seasat* and *Nimbus-7* missions demonstrated the validity of the idea that the ocean surface's shape and color could be measured from space and would be useful. Data from these two satellite missions are still used by ocean scientists.

As part of the Earth Observing System (EOS), NASA plans a major data and information system, the Earth Observing System Data and Information System (EOSDIS). EOSDIS will contribute to the Global Change Data and Information System, a joint venture of NASA, NOAA, and USGS mentioned earlier. Oceanographic data will form an important part of these data systems, and the oceanographic community should ensure that it is well represented on the advisory and management groups for these systems. Beginning in the early 1980s, NASA worked with the academic oceanography community to develop a plan for satellite oceanography and to build a first-class national oceanographic satellite capability. NASA established excellent scientific centers at the Jet Propulsion Laboratory and the Goddard Space Flight Center, and put together an effective headquarters team that oversaw the centers' research and supported research at academic institutions, many of them outside the mainstream oceanographic institutions. This effort, which was endorsed at the highest levels of the agency, led to a period of extremely effective collaboration and joint projects. Both NASA and the institutions learned from each other: NASA, a large federal agency oriented toward massive team efforts extending over many years, and the research community, which is often interested in smaller projects lasting no longer than a graduate student's thesis period.

The investment that NASA made in marine science in the

1980s is about to pay off in a surge of data from missions using satellites that will fly in the 1990s. Considerable expertise and experience now exist both within the NASA centers and in the nonfederal laboratories and universities—almost all of which can be attributed to the far-sighted NASA policies of a decade ago. The only parameter strongly recommended by the ocean community for measurement in the 1990s that is not included in present plans is Earth's gravity field; this oversight needs to be rectified by joint discussions between NASA and the European Space Agency.

As we look beyond the 1990s and well into the twenty-first century, a favorable outlook is not so clear for ocean satellite measurements. In the past several years, NASA has focused primarily on EOS, a series of satellites aimed at contributing to global change research. EOS's task is to provide a wide variety of data in the late 1990s, but limited budgets are reducing the number of instruments and delaying the launch of others. Certain segments of the ocean community have been involved in EOS planning, but the connection is not as broad as it should be. Moreover, the oceans branch at NASA headquarters has been subsumed into EOS planning, thus eliminating the focal point for ocean interests within NASA.

With this lack of focus, it is more difficult for ocean science to be heard regarding ocean priorities in space measurements. As a result of recent EOS downsizing, ocean instruments have lower priority, and the missions needed for broad coverage of ocean parameters in the twenty-first century are not well defined. If long-term planning does not begin soon, the required missions will not be available to provide continuity with missions flying in the 1990s.

Another problem is alluded to in the discussion of NOAA. For climate purposes, long continuous time series of ocean measurements must be sustained. Because of the requirement for open-ended measurements, the measurements resemble operational ones. Traditionally, NASA has asserted that it did not make operational measurements—that the technology would be transferred to NOAA for that purpose; but NOAA has not received adequate funding even for the limited measurements to be made from the polar and geostationary operational environmental satellites. A closer connection is needed between NASA and NOAA in the transition from research to operations. This problem has been identified by several national advisory committees; it was brought to the attention of the responsible interagency committee, the National Space Council, and is being debated there. Because global change research is a national concern, resolution of this problem of transition is urgent.

The transition of NASA technology to Department of Defense (DOD) operational measurements has had mixed success; the microwave radiometer is now operational in the Defense Meteorological Satellite Program, and data are provided routinely to academic investigators. The Navy has flown, and plans to continue to fly, additional altimeters for ocean surface measurements. However, NASA's attempts to work with DOD on the flight of other instruments for surface winds and ocean color have floundered; this area also needs attention.

Because of the importance of oceanography to the Global Change Research Program, NASA should reestablish some mechanism with sufficient stature at headquarters to communicate with the marine science community. NASA should formulate, in collaboration with other agencies and the academic community, a coherent sense of where its long-term responsibilities lie for the overall health of marine science. For example, NASA is the agency that can nurture the special scientific and technical expertise required for the use of satellite remote-sensed data, and it must do so. Partnerships are key; it is more important than ever for the ocean community to develop partnerships with NASA, as it has with other agencies. NASA should help foster these partnerships. Further, NASA needs to recognize the importance of supporting surface-based programs that both directly support and help maximize the scientific returns from its spacecraft.

Department of Energy

The Department of Energy, formed in 1977, is responsible for supporting the development of energy production and conservation technology, the marketing of federal energy supplies, nuclear weapons research and development, energy regulation, and the collection and analysis of data on energy production and use. DOE has carried out marine-related research for many years, most recently as part of its Carbon Dioxide and Coastal Ocean Margins Programs in the Office of Health and Environmental Research. The research focused initially on understanding the fate of radionuclides. DOE marine research is presently concentrated on chemical and biological aspects of the global carbon cycle to understand the fate of the carbon dioxide emitted to the atmosphere as part of energy production and use. In particular, DOE has funded studies of integrated regional biological productivity on the continental shelf, the cycling and transport of organic carbon and nutrients across the shelf, the influence of western boundary currents (e.g., the Gulf Stream) on shelf physics and biological productivity, particle transport processes, and particle burial in basins along the continental margin.

DOE is one of the few agencies to support long-term research in coastal oceanography. Long time series are useful to determine whether the coastal ocean is changing because of anthropogenic influences and to separate directional changes from natural variations. Earlier programs supported the development of in situ instruments to measure optical properties, particle concentration and flux, chlorophyll, and nutrients, allowing important scientific advances. DOE's support of the successful Food Chain Research Group at Scripps Institution of Oceanography is an example of the value of its early academic partnerships.

Somewhat more than a decade ago, Congress assigned DOE the responsibility to collect information and maintain a major data base on carbon dioxide. Interest in carbon dioxide was growing because of the increasing body of theory suggesting a relationship between the greenhouse effect and energy production and supply. As part of the interagency focus on global change research, several programs initiated within DOE in the past few years capitalize on its experience and interests. Two major programs have emerged: the Atmospheric Radiation Measurements (ARM) program and the Computer Hardware, Advanced Modeling and Model Physics (CHAMMP) program. The ARM program is designed to make complete and detailed measurements at strategically chosen sites to enhance our understanding of clouds and solar radiation. The primary focus of CHAMMP is climate modeling. One of its major goals is to advance the speed of climate models by using highly parallel new computer hardware systems, other software techniques, and new algorithms. Many of the major ocean-atmosphere models from around the world are now being compared. In addition, DOE is requesting an increase in the fiscal year 1993 budget for its open ocean research thrust to fulfill its mission to understand the carbon dioxide balance and the ocean's role in this balance.

DOE funds both extramural research and research carried out at its national laboratories. DOE's national laboratory system employs approximately 50,000 people and has a budget of $6 billion to $8 billion. Marine research is a small part of the overall DOE research effort; Brookhaven National Laboratory is the primary site for marine research. As the oceanographic community discusses its approach to the partnership it hopes to forge with DOE, the laboratories should be considered integral participants.

DOE has sought scientific advice on its marine research through workshops, standing committees of the National Research Council, and one-time reviews by NRC panels and other groups. The OSB has reviewed the Coastal Ocean Margins Program, has advised the Carbon Dioxide Program on oceanic carbon dioxide research; and is presently advising the Office of Health and Environmental Research on the application of molecular biological techniques to marine research. The Coastal Ocean Margins Program would benefit from a standing panel of outside experts to help its staff formulate a focused research plan that would build on the agency's strengths in long-term monitoring and regional research. The existing DOE partnerships with academic scientists in the Carbon Dioxide Program and in the area of molecular marine biology appear stronger.

A more general issue for the oceanographic community to consider is where, in light of DOE's missions, new common grounds might lie. There appears to be a genuine interest on DOE's part to enhance or change its role vis-à-vis Earth sciences. The energy implications of marine geology and geophysics research seems to be a natural field for initial discussions. The plans now being developed by DOE for small satellite missions to measure radiation might well be enhanced to include small satellite missions for ocean measurements. There are clearly many other areas in which energy research and energy supply options overlap with ocean science interests. Future partnership discussions with DOE might be aimed at assessing priorities and planning possible interactions in each particular area.

U.S. Geological Survey

The U.S. Geological Survey was established in 1879. Its primary responsibilities are identifying and characterizing the nation's onshore and offshore land, water, energy, and mineral resources; investigating natural hazards (e.g., earthquakes, volcanoes, and landslides); and conducting the National Mapping Program. To achieve these objectives, USGS prepares maps and digital and cartographic data; collects and interprets data on energy, mineral, and water resources; performs fundamental and applied research in Earth sciences to understand Earth processes and their variations in time and space; and publishes and disseminates the results of its investigations in the form of maps, data bases, and reports. The USGS marine program has two components: (1) the Offshore Geologic Framework, and (2) Coastal and Wetlands Processes. The Offshore Geologic Framework components conduct regional scientific investigations aimed at understanding and describing the geologic framework, energy and mineral resources, geohazards, and seafloor environmental conditions of U.S. offshore and other areas that could potentially provide a continued supply of needed resources.

The overall objective of USGS coastal research is to improve our ability to predict coastal erosion, wetland loss, coastal pollution, and the location of marine hard mineral resources through a better understanding of processes and the geologic framework within which the processes operate. Improved predictive capabilities are needed by coastal zone planners and managers and are required for preservation of the nation's coastal resources. Thus USGS marine science activities range from a major systematic mapping of the U.S. Exclusive Economic Zone (EEZ), to deep seismic exploration beneath the seafloor and continental margins, to transport processes within the ocean and in coastal areas. Recent increased focus on the coastal zone resulted from government interest in sea-level rise and pollution. Because USGS participates in many national and international research programs with academic scientists, it has developed effective means for peer review and communication of agency research results. An example of partnerships is the USGS Marine Program, begun in the 1960s. The program located it facilities near academic or oceanographic institutions (i.e., Woods Hole Oceanographic Institution, the University of South Florida, Stanford University, and the University of Washington), which permits sharing of marine infrastructure and human resources. Numerous memoranda of understanding and cooperative agreements with other universities are also in place for specific program tasks and needs. USGS annually conducts a part of its field operations on UNOLS ships.

An expanded partnership between USGS and academia could include the following:

- Increased use of external scientists to review the USGS ocean science program. This process might help to clarify the unique role of USGS in marine research. Aspects of the USGS Marine Program are presently reviewed by the Marine Board and other NRC boards.
- Increased participation of external scientists on collaborative projects. Examples of recent successes include studies con-

ducted in California, Boston harbor, and Louisiana and the participation of academic scientists and students in EEZ mapping cruises.

- Reexamination of USGS marine research goals in light of areas for increasing cooperation with academic scientists.

3

Future Directions in Ocean Sciences

The possibility of and the need for studying the ocean on a global scale provide a major impetus for new partnerships in oceanography. The design and deployment of a global ocean observing system, now being discussed, will be possible only with the cooperation of ocean scientists and governments throughout the world.

THE SCIENCE OF OCEANOGRAPHY

Oceanography, the science of the sea, serves many purposes while deriving impetus from many sources. All of oceanography—physical, chemical, geological, and biological—is driven by scientists interested in advancing basic knowledge. Ocean scientists have made a number of exciting discoveries in the past 30 years that have changed our view of Earth. The discovery of oceanic eddies has been important for an understanding of ocean circulation, propagation of sound in the ocean, fisheries productivity, and other ocean processes. Verification by ocean drilling that Earth's crust is divided into moving plates that are created at mid-ocean ridges and recycled into Earth's interior replaced the traditional view that the surface was essentially static. Discovery of dense colonies of animals and bacteria at some deep-sea hydrothermal vents demonstrated that organisms could thrive in ecosystems based on chemical energy from Earth's interior rather than directly on energy from the Sun. Study of the combined ocean-atmosphere system has provided sufficient knowledge of interannual climate variations that scientists are now able to forecast El Niño climate disturbances months in advance.

Over the next decade, oceanography will continue to provide exciting discoveries by contributing new understanding of Earth as a system and by helping us understand how humankind is altering the system. It is now essential (and possible) to study ocean processes on a global scale. The oceanography of the next decade will take place in the traditional marine science disciplines and at the boundaries of these disciplines. New partnerships among oceanographers working in different disciplines should lead to new discoveries about the ocean's role in climate change, the function of mid-ocean ridges, and coastal ocean processes.

Additional oceanographic studies in the coming decade will focus on how ecosystems affect global cycles of important chemicals and, conversely, how changes in the global environment affect marine ecosystems. Studies of ecosystems at hydrothermal vents and hydrocarbon seeps will refine our ideas about the conditions under which life is possible and about the origins of life. More of the ocean floor must be explored to determine the extent and nature of deep-ocean vents, their ability to support novel organisms, and their importance in global chemical cycles. Continued study of the ocean's chemistry should bring new understanding of the past state of Earth, how ocean processes operate today, and the contribution of sources and sinks of various chemicals. The study of deep-ocean sediment cores will provide more information about past natural cycles of Earth's climate, with which present climate fluctuations can be compared. Oceanographers will achieve a better understanding of the variability of the circulation of the world ocean. The interaction of climate with this circulation is only poorly known, but there is evidence that the transport of surface water to depth can vary greatly even over as short a time as one decade.

Unlike many other sciences driven by scientific curiosity, aspects of marine science have immediate and obvious practical applications. These include, but are not limited to, the control of climate by ocean circulation, chemical and biological reactions to climate change, understanding fisheries productivity, movement of pollutants, and the problem of coastal development in the face of rising sea level. Oceanographers are fortunate to take part in a science that is fascinating, compelling, and intellectually challenging. Oceanography is also a science whose outcome is of immediate societal application and in which the financial stakes are potentially immense, for example, the economic impact of a reliable forecast of a sea-level rise. Because the societal implications of the science are readily apparent to policy makers, they may demand answers to purely practical questions in the short term. This pressure can distort the investment in basic science, undermining the quest for basic understanding that remains key to the long-term solution of practical problems. Thus the functioning of oceanography in the United States should focus both on sustenance of the underlying basic science and on specific answers to practical questions of short-term urgency.

This chapter summarizes the concerns of basic scientists, with some focus on the interaction of basic science with more practical problems. Several themes are common throughout the discussion, which is divided by classical disciplines. First is the growing sense that the basic science now encompasses the global ocean scale. This capability and the need to conduct global-scale studies have led to the planning of large-scale, long-term cooperative experiments. Primarily planned and executed with National Science Foundation (NSF) support, they focus the work of many scientists on global ocean research. These large programs are usually managed through national or international consortia that involve many scientists, agencies, and often countries. Such programs will explore new questions and test new mechanisms for working together in the next decade. Global uncertainties are rapidly moving much of oceanography from the capabilities and interests of single or small groups of investigators for a limited time to the involvement of many individuals, institutions, and governments for decades. Mechanisms must be developed for these new large-scale efforts to be sustained in a scientifically and technically sound manner, by coordinating the plans of other nations, federal agencies, academic institutions, and individual scientists.

Second, all sections of this chapter emphasize the dependence of the subject as a whole continued technical developments. The ocean is remarkably difficult to study, given its size, opacity to electromagnetic waves, and general hostility (e.g., its corrosiveness, high pressures, and turbulence). The health of all disciplines depends directly on the continued development of new tools designed to solve their fundamental sampling problems. In the past decade, oceanographic sampling improved through incorporation of new technologies from other fields, such as remote sensing, material science, electronics, and computer science. A fundamental change arising from the use of these new technologies is an increase in the quality and the volume of data collected. Accompanying this change is a significant increase in each oceanographer's capacity to study ocean phenomena, an increase that raises the costs for each oceanographer's science. As the cost per oceanographer for scientific equipment and facilities has increased, the field has responded with increased sharing of facilities, such as ships and submersibles, and equipment, such as the new accelerator mass spectrometer for carbon-14 measurements. The development and shared use of expensive facilities are likely to continue in the future. Yet even with shared facilities, inflation-adjusted research funding for the ocean sciences has remained nearly constant over the past decade, while the number of Ph.D.-level academic oceanographers has increased by about 50 percent and societal pressures to predict man's effect on the ocean have also increased. The growth in the scientific capacity of each investigator and the number of qualified investigators, coupled with nearly constant funding, has resulted in partial funding for some ocean researchers.

Third, the resolution requirements of oceanographic models and the complexity of model physics have always outstripped the largest computational capability anywhere. As understanding of the ocean becomes more sophisticated, more sophisticated models are required. The nurture of computational capability is reflected across the disciplines.

Fourth, the understanding of the ocean and of the problems of oceanographers has progressed so much in the past several decades that all disciplines are now capable of new accomplishments in a seemingly endless number of areas. The problem is that the potential far exceeds the resources likely to be available, and the difficult task of setting priorities within and across disciplines will be amplified.

The foundation of knowledge about the ocean that is now used in policy decisions was gained largely through Office of Naval Research (ONR) and NSF investments in basic research over the past several decades. Yet the demand for quick answers to purely practical questions sometimes obscures the need for investing in basic science, which remains the key to long-term practical applications. Under pressure to provide immediate solutions, mission agencies may be tempted to focus only on the short term. One example of the importance of basic research is a 1961 study that is now contributing to the debate about climate change—the question of whether ocean circulation has two stable states. Both the geological record and numerical models suggest that, at some times in the past, ocean circulation was unlike today's and that it could switch rapidly from its present state to a radically different one. When the ocean was in this alternate state, Earth's climate was not at all like today's. This idea dates back to a paper written by Henry Stommel (1961), an academic scientist driven primarily by his own curiosity and supported by ONR and NSF. The paper had little impact for more than 20 years. Now regarded as seminal, it illustrates the need to sustain basic science so that future generations will have a knowledge base from which to develop their policy decisions.

The authors of the following sections were asked to discuss the dominant issues of their disciplines and to lay out the grand themes, providing a scientific underpinning to discussion of the new partnerships. Ten years is probably the outer limit of an attempt to suggest what the major science themes will be. A decadal report written in 1960 would almost surely have missed the revolution in plate tectonics and thus would have been hopelessly wrong in its discussion of some dominant scientific themes in 1970. On the other hand, such a report could have captured accurately the methodologies of work at sea and the human resource requirements. Of course, the central questions of the field did not change either—although an intellectual revolution in the way they could be discussed occurred.

The decision to organize this chapter according to traditional oceanographic disciplines was not arbitrary (the coastal ocean is a special case, discussed below). Anyone who reads each section will perceive exciting and important scientific problems that cut across many or even all disciplines. Examples are the growing importance of paleoceanographic studies that involve geology, geophysics, chemistry, biology, and physical oceanography because of their climate implications. Likewise, the study of ridge crests cuts across geology and geophysics, biology and chemistry, and even slightly, physical oceanography. Nonetheless, the board believes that there is a danger in declaring such interdisciplinary studies as the likely focus of future marine science efforts. Without denigrating the science done on such problems, interdisciplinary studies clearly build on the foundations of chemistry, physics, geology, geophysics, and biology. These, in turn, depend directly on their nonmarine counterparts of physics, mathematics, numerical methods, and other fields that provide the intellectual fertilization of marine studies. The history of ocean sciences suggests that one cannot have good interdisciplinary science without good disciplinary foundations, and it is essential that the traditional oceanographic disciplines retain their identity and vitality. One needs to encourage scientists working on interdisciplinary problems, but they must first be expert in one or more of the basic disciplines. Just how such fostering should take place is the subject of debate, and the reader will detect a degree of disagreement as to how we should move forward. Working out various combinations of scientists and institutions is a major challenge for our academic institutions in the next decade. The board makes no specific recommendation except to note that the strength of the U.S. scientific community is its ability to tolerate and encourage great diversity in its institutions.

Because the following sections were written by a number of different authors, they differ in style and content. The sections are not meant to be all inclusive but instead to provide a flavor of the excitement of each discipline of oceanography.

The treatment here of coastal oceanography is anomalous because it deals with a geographic region—that is, shorelines, estuaries, bays, and the continental shelf—and not a discipline. The large percentage of the U.S. and world population that lives in the coastal zone, and the multiple human uses and impacts on the coastal ocean, place this area of oceanography much more conspicuously and immediately in the public policy arena. Unlike the participants in deep-water marine science, states, cities, and private enterprise are all prominent players in understanding and using the coastal ocean. The interplay of the basic sciences of fluid flow, chemistry, biology, shoreline physics, and geology with public policy concerns leads to a near-term urgency that cuts across scientific disciplines. However, it is important to recognize, as this report does, that the foundations of understanding must rest firmly on the underlying basic sciences.

DIRECTIONS FOR PHYSICAL OCEANOGRAPHY

Summary

The great volume of water in the ocean exerts a powerful influence on the Earth's climate by absorbing, storing, transporting, and releasing heat, water, and trace gases. The goal of physical oceanography is to develop a quantitative understanding of the ocean's physical processes, including circulation, mixing, waves, and fluxes of energy, momentum, and chemical substances within the ocean and across its boundaries. Addressing such problems will require sustained large-scale observations of the world ocean aided by advances in measurement and computational technology. Designing and deploying a global ocean observing system are among the most important and difficult tasks for physical oceanography and climate studies for the next decade. Such a system would incorporate existing measurement programs as well as observations that are not yet routine.

Several topics will dominate physical oceanographic research in the coming decade. Research in modeling, ocean mixing, thermohaline circulation, and water mass formation processes will be important. To achieve their scientific objectives and to make more complete ocean observations, physical oceanographers must use both proven methods and new technologies, including acoustic techniques; measurements made from volunteer observing ships; satellite observations and data relay; and measurements of the distributions of trace chemicals.

Introduction

The ocean consists of nearly 1.4 billion cubic kilometers of salty water, about 97 percent of the free water on Earth. In comparison, the atmosphere holds only about 0.001 percent. This volume of water exerts a powerful influence on Earth's climate by transporting heat, water, and other climate-relevant properties around the globe and by exchanging these properties, as well as greenhouse gases (e.g., carbon dioxide, methane, and chlorofluorocarbons), with the atmosphere. Net ocean absorption of greenhouse gases and some greenhouse-induced heat from the atmosphere can delay greenhouse warming of the atmosphere. Predicting future climate conditions depends on learning what controls ocean circulation and water mass formation, and whether the system is predictable, even in principle.

Physical oceanography, like many fields of science, consists of theory, observations, and numerical models. Physical oceanographic theories use the equations of fluid dynamics, modified to account for Earth's rotation and shape (e.g., O'Brien, 1985). A goal of physical oceanography is to develop a quantitative understanding of the ocean circulation, including fluxes—of energy, momentum, and chemical substances—within the ocean and across its boundaries. Physical oceanographers must contribute to the increasing societal emphasis on measuring, predicting, and planning for changes in global climate by improving understanding of the physical factors that maintain the overall physical, chemical, and biological characteristics of the ocean. Advances in measurement and computational technology will continue to contribute to advances in physical oceanography.

Studies of climate change put the skills of oceanographers to a severe test. The time scales are long: interannual, decadal, and beyond. Physical processes are three dimensional and involve interaction of the ocean with the atmosphere. Winds transfer momentum and promote mixing and evaporation. Atmospheric temperature influences the density of ocean surface layers through effects on seawater temperature and salinity (through ice formation and melting), which in turn modify the atmosphere. Development of the physical state of the ocean is difficult to model because it involves the complex interaction of processes that operate on vastly different time and space scales. Nonetheless, progress is being made. Techniques that will permit better and more frequent observations are being developed, and advances in numerical modeling will soon permit representation of the major components of ocean circulation.

Ocean observations reflect the state of the ocean and hence the forces acting on it. Because observations are made in a corrosive, turbulent environment with high pressures at depth, they are difficult and expensive to obtain. Because of the size and variability of the ocean, measurements are always incomplete in space and time. Yet understanding the ocean depends on adequate measurements, and to make them we need to use technologies that permit a view of the global ocean. Technologies based on acoustics, space-based remote sensing, and underway automatic measurements could all be applied to global-scale observations.

Predictions of the ocean can be carried out only when the initial and boundary conditions are provided from observations with an accuracy and precision consistent with the physics present. Because oceanic observations are so expensive, models and theories must be used to help determine the most cost-effective measurements and measurement systems.

Global Ocean Observing System

Physical oceanographic observations and modeling are becoming global, but the resources required to deploy and sustain large-scale observations of the world ocean are enormous. The exact configuration of a global ocean observing system is unknown, but it would probably include existing observations from satellites, moored open ocean sensors, volunteer observing ships, and the global sea-level network, as well as other observations that are not yet defined or collected routinely. The scientific and technological results from several ongoing large-scale research programs—the Tropical Ocean-Global Atmosphere program, the World Ocean Circulation Experiment (WOCE), and the Joint Global Ocean Flux Study—should be used to design an operational observation system that is effective, affordable, and consistent with our knowledge of the scales of ocean biology, chemistry, and physics. It would be the largest field enterprise ever undertaken by the oceanographic community, and it must have an international and multidisciplinary scope well beyond previous experience. The design and implementation of a global ocean observing system (GOOS) must involve ocean scientists substantially because the design is extremely important to the science itself and depends on firm scientific understanding. Designing and deploying a GOOS is one of the most important and difficult tasks for physical oceanography and climate studies in the next decade. The United States should take a major leadership role in both the research and the operations.

Because of the present paucity of ocean data, numerical models are important in the development of a GOOS. Models will be used to interpret available data for testing possible system designs and, ultimately, to interpret the data from such a system.

Major Research Topics for the Coming Decade

Several topics will dominate physical oceanographic research in the coming decade. The list is incomplete; the topics mentioned received some emphasis during the Ocean Studies Board workshops as representing key research issues and include the following: research in modeling; ocean mixing, including interior mixing and the surface mixed layer; thermohaline circulation; and heat and freshwater fluxes.

Ocean Modeling

The central focus of numerical modeling of the ocean has been, and continues to be, directed toward fluid dynamics, but the models have importance far beyond physical oceanography. For example, communities of organisms in the upper ocean live in a delicate balance, depending on the stability of the water column, its mixing rates, and its large-scale vertical and horizontal fluid movements. Our limited ability to predict the movements of the upper ocean limits understanding of basic biological processes.

The transfer of gases between atmosphere and ocean is central to the carbon cycle; this transfer relies on many scales of circulation and mixing.

Combined atmosphere-ocean simulations at interannual time scales require more accurate ocean models. The present generation of coupled atmosphere-ocean models exhibits unacceptable drifts (Manabe and Stouffer, 1988). Climate forecast models must be free of even small systemic errors that accumulate over long simulated periods, hiding the signals that are sought. To understand and mimic the paleoceanographic record, a major test of global models, one must be able to carry model integrations over time scales corresponding to thousands or tens of thousands of years. It is not clear that ocean and atmosphere behavior is predictable on scales of decades or longer. The limits of predictability are being explored as a research topic.

The global ocean is so large and its circulation occurs over such a variety of space (tens to thousands of kilometers) and time (days to centuries) scales that ocean circulation modeling has always overwhelmed even the largest supercomputers. This situation will probably remain for some decades to come. Thus it is a major intellectual challenge to design models of ocean circulation with time and space increments small enough to model processes adequately, given foreseeable limitations in computing resources.

Prominent features and processes that must be incorporated more accurately into physical oceanographic models (in a manner consistent with observations) include the effects of complex bottom topography on deep-water masses, deep vertical and horizontal mixing, eddies and fronts in the upper ocean, the interaction of water flow and diffusion of a variety of properties, boundary effects at the seafloor and surface, and the dynamics of shallow and deep boundary currents.

Ocean Mixing

Interior Mixing Large-scale ocean circulation is coupled with, and partially controlled by, small-scale mixing processes. Understanding the places, rates, and mechanisms by which the ocean mixes heat, salt, and momentum is crucial to understanding the circulation of the largest scales and essential to any capability to predict future oceanic states. It is intimidating to realize that to understand the dynamics of large-scale circulation and convective water mass formation, we must also understand the physics acting on the smallest scales (centimeters and millimeters). Heating, cooling, flow, and mixing processes act together to determine physical properties of the ocean. Changes in any one of these processes can affect the global climate system. Significant progress in the observation of ocean mixing processes and in the interpretation of these observations has been made, but understanding remains inadequate.

The capability to compare direct mixing measurements (through microstructure and purposeful tracer releases) with natural mixing (estimated indirectly from natural tracer distributions) is rapidly accelerating our understanding of mixing processes (Watson and Ledwell, 1988). The results of such comparisons will direct future research. For example, if deep-sea observations confirm that mixing rates are lower than predicted, attention will focus on mixing processes in the benthic boundary layer and continental slopes. If tracer studies indicate significantly more mixing than is seen by direct measurement, double diffusive and other mechanisms will be explored. With new observational techniques and a clear measurement strategy, significant progress can be expected in the coming decade in the study of ocean mixing.

Surface Mixed Layer The primary production that supports the entire marine food web occurs in the upper sunlit portion of the ocean (the euphotic zone), where photosynthesis occurs. Our growing concern for climate variation makes understanding the uptake of carbon dioxide related to photosynthesis of particular importance. Fortunately, several developments over the last few years in biological oceanography, marine chemistry, and ocean physics promise advances in the study of the biological-chemical cycles in the euphotic zone. Exploitation of new techniques could significantly improve our ability to predict various aspects of global environmental change, including the ocean's role in sequestering carbon dioxide.

The topmost layer of the ocean is called the "mixed layer" because the waters are mixed by wind, waves, and currents. This layer is often nearly homogeneous in temperature and chemical characteristics, and is bounded by the sea surface and a layer of denser water. The transfer of gases between atmosphere and ocean depends primarily on mixed-layer processes. Understanding the physics of the ocean surface mixed layer, and its coupling with the ocean interior and the atmosphere, is essential if the combined biogeochemical systems of ocean and atmosphere are to be represented correctly in ocean models. Mixed-layer studies are among the endeavors of physical oceanography in which strong interaction with the fields of biology and chemistry is particularly rewarding. The rates of heat, water, gas, and momentum exchange across the ocean-atmosphere interface must be estimated better from easily measured or calculated environmental parameters (e.g., wind, temperature differences across the air-sea interface, waves, and stability of the mixed layer).

Because photosynthesis involves the conversion of carbon dioxide and nutrients into living material and oxygen, the euphotic zone is an immediate sink for atmospheric carbon dioxide. The flow and mixing of water masses and the transport of nutrients and particles that control phytoplankton populations depend on physical oceanographic processes. Understanding the mixed layer is a complex problem involving studies in marine biology, chemistry, and physics. In a crude sense, the mixed layer can be regarded as controlled by a set of chemical reactions in which biological processes determine most of the reaction rates (nutrient fixation and regeneration) and physical processes (advection, mixing, and particle sinking) determine the rates at which reactants and products are provided to or removed from the system.

The physical oceanographer's approach to studying the surface mixed layer involves measurement of currents and horizontal variations to determine advection, microstructure measurements to study turbulent fluxes, and measurements of deeper properties to infer vertical flows. Chemical oceanographers study the latter process using time-dependent tracers to estimate the vertical path of water masses and observe changes along it. Both methods can be strengthened by a model that integrates the measurements.

Thermohaline Circulation In a few limited regions of the ocean, a combination of low temperature and high salinity produces dense surface water that flows into the deep ocean and spreads laterally to initiate global-scale thermohaline circulation. Deep-reaching convection occurs in the northern North Atlantic Ocean and around Antarctica. These water masses spread throughout the ocean and force deep ocean water, which has been made more buoyant by the downward diffusion of heat, to upwell slowly. Eventually, the upwelled water migrates back to the sinking regions to complete a thermohaline circulation cell (see Gordon et al., 1992). Water masses formed in different regions vary in terms of temperature, salinity, nutrient concentrations, and stored carbon content. The relative contribution from each source region determines the ocean's average temperature, salinity, and other properties, such as carbon storage. In addition, this downward flow of surface water provides a link between the atmosphere and the deep ocean. Thus a better understanding of the global climate system requires a detailed understanding of the thermohaline circulation, its vulnerability to change, and the processes that govern water mass formation rates. Once these factors are understood, they can be represented in global ocean and climate models.

There is evidence that surface salinity fluctuations in the high-latitude North Atlantic Ocean control the thermohaline circulation by altering North Atlantic Deep Water (NADW) formation. One possible mechanism to slow NADW formation is capping of the ocean surface with low-salinity water, such as Arctic Ocean waters (Weyl, 1968). During the last century, there were at least two episodes of low surface salinity water in the northern North Atlantic Ocean [the latter during the late 1960s and 1970s is referred to as the great salinity anomaly (Dickson et al., 1988)] that drastically reduced or stopped convection and NADW production. Changes in the twentieth century are very small compared to suspected changes in NADW formation rates during the swings between glacial and interglacial periods (Boyle, 1990).

The Indian Ocean is a strongly evaporative ocean. Lacking a northern polar region, the tropical heating of the Indian Ocean cannot be vented by flow to the north. Strong evaporation in the Red Sea and Persian Gulf forms warm salty water that, like the Mediterranean outflow, is small in volume but adds significant heat and salt to the deep ocean. The role of the Indian Ocean in larger-scale thermohaline circulation remains unclear and should be studied in the coming years.

The sea ice cover of the Southern Ocean acts to decouple the ocean from the atmosphere, limiting cooling of the ocean by the polar atmosphere. The insulating blanket of sea ice protects the ocean from the cold atmosphere. The extreme seasonality and rapid spring melting of the Southern Ocean sea ice cover suggest that the heat carried into the surface layer by the upwelling of deep water is a key in understanding the Southern Ocean sea ice budget; the buildup of heat within the mixed layer under the winter ice cover induces melting even before solar radiation melts the ice from above. Ocean heat flux also limits sea ice thickness during the winter to less than 1 meter, in contrast to the 3-meter ice of the more stable Arctic Ocean.

Heat and Freshwater Fluxes The ocean interacts with the atmosphere in affecting the heat and freshwater fluxes that control the climate system. Estimates of the fluxes to and from the ocean and atmosphere are difficult to obtain with adequate accuracy, and at the present time there are serious conflicts among values estimated from atmospheric models and data, from oceanic models and data, and from the boundary layers in the two media.

The ocean and atmosphere contribute roughly equally to the transport of heat from lower latitudes toward the polar regions—a transport that is required to maintain the global radiation balance at the top of the atmosphere—although the relative importance of the two transport mechanisms varies with latitude. The massive amounts of water moving in the ocean render it a crucial transporter of moisture, but we have little idea of the sizes of freshwater sources and sinks over the ocean (Baumgartner and Reichel, 1975). Their distribution must have profound effects on the distribution of rainfall over land, an important component of the climate in habitable regions of the world. Low surface salinity caps the ocean, attenuating convection and deep-reaching water mass formation. High surface salinity, combined with surface cooling, allows deep convection and ventilation of the interior of the ocean.

We need to monitor changes in ocean surface salinity globally. Satellite sensors monitor sea surface temperature and its anomalies, but monitoring sea surface salinity and its anomalies on a global scale is beyond present capabilities, as is determination of the temperature below the very surface.

Over the last decade, oceanographers have begun making direct estimates of the north-south ocean heat and freshwater transports using transoceanic hydrographic sections and modern measurements of strong boundary currents and then comparing them with the more uncertain indirect estimates based on atmospheric data. To understand heat and freshwater transport fully, oceanographers must describe the general ocean circulation and its variability. It is discouraging, however, that since 1985, only six transoceanic hydrographic sections, the backbone of the observations needed to determine the north-south fluxes, have been carried out: at 47°, 24°, and 10° north latitude in the Pacific; 32° south latitude in the Indian Ocean; and 11° north latitude in the Atlantic. Overcoming organizational and funding obstacles for these long hydrographic sections takes major effort by individual scientists. However, WOCE has plans to make the necessary measurements for determining the ocean heat transport in each ocean basin at several latitudes (WOCE Scientific Steering Group, 1986). This work is a central focus of WOCE and is clearly needed if understanding of how the present climate system works is to progress.

Provision for continuing such observation beyond the end of WOCE is essential.

Methods

To achieve their scientific objectives, physical oceanographers must use both proven methods and new technologies to make more complete ocean observations.

Volunteer Observing Ships The maritime industry is a resource for ocean research and monitoring that can no longer be viewed as simply an adjunct to the academic research fleet. On the contrary, its integration into a global ocean observing system would provide far greater and more frequent access to the ocean than will ever be possible with research vessels alone.

Volunteer observing ships (VOS) offer opportunities to study and monitor the ocean with a coverage and frequency that are unthinkable by any other means. With the advent of new and more sophisticated remote sensing techniques, such as ocean color scanners, altimeters, and scatterometers, it is plausible that the demand for direct observations will increase, for several reasons. First, the need for calibration measurements will grow. Second, the ocean color scanner will observe numerous signals that require in situ samples for identification, interpretation, and analysis. Third, as coverage of the ocean surface improves, a concomitant need for improved subsurface coverage is inevitable.

Without doubt, a major impediment to the use of VOS is the lack of automated instrumentation for nonscientists on moving commercial ships. Most instruments are designed for trained personnel on research vessels equipped with laboratories. A new approach to the VOS concept is needed. It will require discussions and planning with the maritime industry internationally to develop new modes of cooperation. The community must think of VOS as a potential platform, and ship operators must be persuaded that oceanographic work is to their benefit. At the same time, the development of instrumentation optimized for use on VOS must be encouraged, including the following:

- Modern sensor packages are needed that can be dropped and retrieved repeatedly along a ship's route to measure salinity, oxygen, and fluorescence (primarily from phytoplankton). Data obtained by the sensors could be transferred to a small on-board computer for analysis and transmission to data centers.
- Disposable free-falling sensor packages should be developed

that travel to great depths and transmit their data via acoustic signals or return to the surface and broadcast to satellites. Sensor packages could transmit data for any ocean observation that can be measured in situ. Disposable sensor packages can transmit data via a thin wire that detaches when the sensor reaches its maximum depth, but free-falling sensors could travel much deeper and measure more accurately than present devices.

- VOS could tow instruments to measure various ocean characteristics. When ship routes and sampling locations coincide, passing ships could retrieve data from moored instruments (e.g., moored current meters and inverted echo sounders) by acoustic signals. At the least, commercial ships equipped with acoustic Doppler current profilers could measure upper ocean currents and heat fluxes routinely.

Remote Sensing by Satellite Satellites observe vast areas of the ocean surface daily, obtaining data at a far faster rate than surface vessels and instruments (e.g., Stewart, 1985). Satellites also aid physical oceanography by transmitting data gathered by in situ ocean sensors combined with highly accurate positioning information. The availability of surface and subsurface instruments has greatly increased the volume of data beyond that possible from ship-based observations, and the instruments provide valuable time-series data.

Satellite sensors are used to map natural infrared and microwave radiation emitted from the sea surface. Infrared radiation provides images of sea surface temperature patterns. Radiation in the microwave frequencies is used to map sea ice distribution in areas of the globe that are otherwise poorly accessible. Phytoplankton blooms can be monitored from space with sensors that respond to the visible and near-infrared radiation reflected by plankton chlorophyll, integrating the effects of temperature, nutrients, and the physical structures and processes of the ocean surface layer. Suspended sediment is also measured by visible sensors. Surface winds are measured by satellite scatterometers. The sea surface slope can be measured from space by radar altimeters with accuracies adequate for determining many features of ocean circulation. This is the only practicable method for global-scale continuous observation of circulation. Synthetic aperture radar on satellites can measure sea state, internal waves, and ice conditions with very high spatial resolution.

Although satellite data yield a nearly continuous view of the ocean, it is important to note that complementary in situ observations from ships or instrumented drifters are required to improve the mathematical relationships (algorithms) for calibrating satellite observations to in situ values.

A suite of satellites launched by the United States, the European Space Agency, and Japan and with many joint satellite missions should provide many data required by physical oceanographers during the next decade. Advances in physical oceanography are tied closely with satellite views of the ocean and telemetry of data from Earth's surface. Coordination of satellite projects with ocean science objectives and in situ ocean measurements is required. The satellite time series of sea surface temperature, winds, sea ice, ocean color, and ocean height must be continued without interruption to provide a complete record of their variability.

Tracers Distribution of ocean properties can be used to depict the pattern of ocean currents and the effects of mixing within the ocean because water masses from different source regions vary in their physical and chemical signatures. Traditionally, temperature, salinity, oxygen, and nutrient concentrations have been used to track the movement or spreading of ocean water masses. Other more exotic chemicals present in minute concentrations (tracers) are now commonly used to track water masses. For example, chlorofluorocarbons, carbon-14 and tritium from atmospheric nuclear bomb testing, and other natural and synthetic substances with known rates and times of input to the atmosphere have been used as tracers. Tracers average the spreading action of ocean circulation at a variety of scales and integrate the effects of many processes. The infiltration of naturally occurring and synthetic chemical tracers into the ocean provides insight about the time scales of ocean circulation and mixing. The development of baseline time series of tracer concentrations is important.

Acoustic Techniques Because the ocean is transparent to sound but opaque to light, acoustic techniques provide oceanographers with the opportunity to see the interior of the ocean. In a real sense, the hydrophone array serves as the underwater eyes and ears of the oceanographer. The enormous bandwidth of available underwater acoustic instrumentation (10^{-3} to 10^{6} hertz) allows sound to be used as a probe of structures and processes whose scales range from millimeters to ocean basin scales. The ocean is especially transparent to low-frequency sound. Consequently, underwater sound is becoming an important means of studying the three-dimensional structure of the ocean below its surface. Continuous measurements of current velocity from shipboard acoustic sensors give a two-dimensional record of ocean currents to several hundred meters. Acoustic techniques are also used to track subsurface floats and transmit information between ships and sensors at depth. Yet, sound is an underemployed tool in oceanography. Significant advances should be made during the next decade in physical, biological, and geological oceanography as a result of thoughtful application of acoustic principles and techniques for direct probing and information transfer. Because of its inherent global nature, the acoustic monitoring of ocean climate is a strong candidate for a global ocean observing system.

The air-sea interface provides a variety of challenges and opportunities to the oceanographer using acoustic techniques. The formation and subsequent collapse of bubbles are important sources of sound whose monitoring could provide an estimate of wave breaking intensity from which gas transfer rates could be inferred. Such measurements give important insight into poorly understood sea surface physics. The passive measurement of rainfall-generated sound is a way to measure precipitation in the open ocean. Direct measurement of precipitation is difficult to obtain and generally inaccurate. Better measurements of precipitation over the ocean are important because of its effect on the global heat and water budgets.

Some of the oceanographic applications of underwater sound are simple. Others will require improvements in our understanding of the physics of sound propagation in the sea and improved signal processing techniques and instrumentation.

DIRECTIONS FOR MARINE GEOCHEMISTRY

Summary

Studies of chemicals dissolved in seawater, adsorbed on suspended particles, incorporated in living or nonliving organic material, and buried in seafloor sediments have yielded much information about Earth processes and past conditions. Environmental conditions are imprinted on particles that fall to the seafloor and are buried over time. With adequate understanding about processes that affect chemical concentrations and forms after deposition, sediments recovered by seafloor drilling can illuminate Earth's environmental history for millions of years into the past. In addition, modern ocean processes can be studied by measuring the concentrations of trace elements and compounds in seawater. For example, measurement of trace element distributions is a major tool used by physical oceanographers to study ocean circulation.

The ocean is a chemical reactor, with inputs, internal reactions, and outputs. Inputs are received from continents via rivers and airborne transport. Other chemicals enter the ocean from hydrothermal sources, primarily at mid-ocean ridges. As oceanic crust is subducted beneath continents, elements are expelled from both the crust and its overlying sediment layer. Finally, a minor proportion of input to the ocean comes from cosmic sources. Inputs are the least understood part of the reactor.

Elements are redistributed in the ocean by circulation and mixing, and are transformed through chemical reactions and biological activity. Chemicals finally exit the reactor through incorporation into seafloor sediments. The residence time of chemicals in seawater and in the sediments depends on properties of the chemicals, as well as chemical, physical, and biological conditions. Chemical oceanographers seek to understand the present reactor and then, from examination of changes in the outputs over time, determine variations in the reactor's behavior and the compositions and fluxes of inputs in the past. With this information, the limits of future oceanic changes under given climatic and tectonic scenarios can be estimated.

Future studies in chemical oceanography will be aided by new instruments that are capable of analyzing a wide variety of elements and isotopes contained in small samples. Greater knowledge of processes controlling fluxes, redistribution, and removal, and improvements in our ability to read the sedimentary record are likely in the coming decade.

Introduction

Marine geochemistry integrates several oceanographic disciplines. The aims of marine geochemistry are (1) to understand the inputs of elements from the continents, mantle, and cosmic sources into the ocean over time; (2) to understand the process of material removal from the ocean to the sediments and oceanic crust; (3) to understand the process by which elements and their isotopes are redistributed; (4) to determine the mechanisms of chemical coupling between the ocean and the atmosphere, and interpret the sedimentary record of past oceanic change; and (5) to study marine organic compounds both in their relation to the above factors and to the global carbon cycle, and as detectors of oceanographic properties over time.

Oceanic sediments record environmental events over the past 180 million years of Earth's history. Ocean water in which sediment particles are formed or through which they pass is both an agent of transport and the site where information about environmental conditions is imprinted onto components that eventually become part of marine sediments. Geochemical signatures in the sediments complement the sedimentological and paleontologic record in special ways. Oxygen and carbon isotopes in marine calcareous shells or tests and organic remains provide insight into ocean surface temperatures, ocean circulation, and the extent of ice storage in past glaciations. Trace elements such as cadmium and barium add to our understanding of deep-ocean circulation and upwelling. Isotopes produced by cosmic rays, those originating from uranium decay, and those produced or enhanced by human activities, provide information on chronology, sediment properties, oceanic upwelling, deep-water formation, and transport of elements. The unique properties of the isotope ratios $^{87}Sr/^{86}Sr$, $^{206}Pb/^{207}Pb$, $^{143}Nd/^{144}Nd$, and $^{187}Os/^{186}Os$ permit insights into the geologic questions of plate tectonics because the isotopic composition of seawater reflects the isotopic composition and relative importance of each source, for example, material derived from the mantle and continental rock weathering.

Although present in greatly diluted concentrations, marine organic substances play a key role in the global carbon cycle as modulators and tracers of oceanic processes. For example, organic remains account for approximately 20 percent of all carbon buried in marine sediments and thus are an important sink for atmospheric carbon dioxide. The burial of organic matter and its subsequent oxidation essentially control atmospheric oxygen levels over geologic time. Dissolved organic matter in seawater may contain a mass of carbon comparable to that in terrestrial biomass and could potentially affect atmospheric carbon dioxide concentrations on a time scale of a thousand years—the ocean's turnover time. In addition, organic molecules in particulate and dissolved forms are important vehicles for the transport of reducing power, nutrients, and trace elements throughout the ocean and across the air-sea and sea-sediment interfaces. Organic molecules in the marine environment are couriers of unique information about the sources, pathways, and histories of the associated particles and water.

The Ocean Reactor

The ocean receives dissolved and particulate material from a variety of sources and pathways. Traditionally, river inputs were regarded as the major contributor of dissolved material. Wind transport of dust was recognized as adding to the particle flux borne by streams, and the input of altered volcanic material to deep-sea sediments was clearly identified by the 1960s. Within the past 15 years, deep-sea hydrothermal activity, predominantly at spreading centers, was found to be important as both a source and a sink of elements. In addition, a significant flux of dissolved material may be expelled from sedimentary wedges and underlying oceanic crust as they descend into the mantle through subduction zones. Cosmic dust and cosmic ray-produced nuclides are not a major input to the ocean in terms of volume, but are important as tracers and for understanding episodic influxes of significance to the history of our planet.

Elements are redistributed within the ocean in dissolved form by horizontal and vertical advection, diffusive mixing, and incorporation into particles. Chemical species are removed from the ocean as particles settle to the seafloor; they also react directly with the seafloor as the result of diffusion and circulation through sediments and the oceanic crust. Seafloor sediments and altered rocks undergo secondary reactions over time, and their composition may change substantially. From a chemical point of view then, the oceans are a large chemical reactor with multiple feeds and outputs. Chemical oceanographers want to understand the present reactor and then, from examination of changes in the outputs over time, determine variations in the reactor's behavior and the compositions and fluxes of inputs in the past. With this information, the limits of future oceanic changes under given climatic and tectonic scenarios can be estimated.

Geochemical study of the oceanic water column and the output of elements to the sediments is now relatively mature. The descriptive phase is largely complete, and studies of mechanisms are growing more numerous. For inputs of elements to the ocean, however, quantitative research is difficult and, in the case of inputs from the continents, may not correctly reflect disturbances in terrestrial inputs caused by humankind. These disturbances have occurred on time scales of a few years to several centuries, and the ocean has not yet equilibrated to the altered inputs.

Fluxes

Quantitative measurement of river inputs is difficult because measurements of fluid discharge from rivers are uneven in quality, frequency, and distribution. Because the best data are available from developed regions of the world, they do not necessarily represent areas less impacted by human activities.

Many of these same uncertainties apply to airborne inputs. Transport is strongly seasonal and diffuse, and thus is difficult to measure. Wind erosion rates are sensitive to the nature of the land cover and therefore to changes in land use. Windborne particles efficiently scavenge volatile chemicals released to the atmosphere by volcanism, biomass burning, and industrial activities. Thus the chemical composition of windborne dust is sensitive to pollution. In addition, photochemical reactions occur in the atmosphere, changing the chemistry of the atmosphere and particle-bound chemicals.

Hydrothermal activity in the deep sea is driven by volcanic processes in the oceanic crust, predominantly at spreading centers. Seawater seeps into crustal rocks, entering convection cells in the rocks, and is heated to 300 to 400°C. In the course of this circulation, elements in the seawater react with the hot basaltic rocks; some chemicals are removed (e.g., magnesium, sulfate, and uranium) and others are added (e.g., mobile elements and gases). The fluxes of elements at any one site are difficult to quantify, and it is not feasible to measure the thousands of sites that differ in rock temperature and composition. To account for observed isotope concentrations in seawater (e.g., strontium), a volume of water equal to the world's ocean must circulate through the hydrothermal system at temperatures above 325°C every 10 million years. However, estimates of hydrothermal circulation based on heat lost in the formation of the oceanic crust are about five times lower. If the higher estimate for hydrothermal circulation is correct, this process is as important as rivers for the input of many elements to the ocean. Hydrothermal processes would stabilize seawater composition and thus act as a geochemical flywheel, potentially damping large-scale changes induced by long-term climatic and tectonic changes. Yet, if the lower estimate of hydrothermal circulation is correct, hydrothermal activity is a minor factor in the cycling of ocean elements and is important for only a few. The major inconsistency between the fluxes based on isotopic and thermal constraints, apparent since the first hot springs were found in the deep sea 15 years ago, remains to be resolved.

There is evidence that hydrothermal circulation at relatively low temperatures (a few tens of degrees) away from spreading centers may also be important for fluxes of elements. However, it is not yet possible to calculate even the vaguest estimate of the chemical fluxes involved. Recent seafloor exploration and ocean drilling show that the ocean crust and its overlying sediment expel water in the subduction process. Given the great compositional and tectonic diversity of active subduction zones, it will be impossible to estimate the geochemical significance of these processes to the oceanic element cycles until much more exploratory work has been done.

Redistribution

All the inputs will react with seawater. Reaction processes in the zone of mixing between river water and the upper ocean are quite well described qualitatively. These processes include desorption of elements from suspended particles, coagulation and precipitation of colloidal material, scavenging by organisms, and vertical transport. Processes associated with the formation of particle plumes above hydrothermal vents have been studied extensively. These particles oxidize rapidly and appear to scavenge both a large proportion of the hydrothermically transported trace metals and a significant component of elements from ambient seawater.

As mixing progresses, ocean circulation is increasingly dominant in dispersing inputs until they cannot be traced directly back to their source. Large rivers can be considered as point sources of material to the ocean superimposed on a diffuse background input from smaller streams. Penetration of the river signal into the deep sea follows complex pathways that are regionally diverse, depending on the current regime and the configuration of the coastline and the continental shelf. Because even unpolluted rivers usually carry elevated nutrient loads relative to coastal seawater, their discharge induces large phytoplankton blooms. The phytoplankton settle toward the seafloor, carrying nutrients and scavenging dissolved substances. In confined systems with high nutrient inputs, settling organic material can fuel bacterial activity and lead to oxygen depletion of bottom waters. The complex coupling of inorganic and biological processes, postdepositional reactions in the sediments, and strong seasonality of inputs produce a system whose chemical transport is difficult to quantify. Estuarine processes make it difficult to estimate river inputs of the more reactive elements to the open ocean. Because of this complexity, chemical oceanography in the coastal ocean has been relatively neglected even though that is the site for some of the most intense biogeochemical interactions in the entire ocean.

High-temperature hydrothermal fluids create great buoyant clouds of fine-grained sulfides and oxides upon their turbulent injection into the surrounding water column. These clouds rise above the vents until their density equals that of the surrounding seawater. On ridges with high rift walls (e.g., the Mid-Atlantic Ridge), the plumes often stay within the confines of the bounding rift walls. The precipitates and dissolved material they scavenge then accumulate on the walls and floor of the rift valley. On fast-spreading ridges with low walls (e.g., the East Pacific Rise), the plumes rise above the walls and are dispersed in the middepth circulation. Fine-grained vent-derived particles can be transported for thousands of kilometers, slowly settling out to form a compositionally distinctive shadow in the sediments. Unreactive species, such as helium, delineate plume flow.

If redistribution of elements occurred only by the physical dispersal of dissolved material and suspended particles near their sources, geochemical patterns would be related solely to input functions. However, the chemistry of the ocean reactor is determined primarily by organisms and chemical kinetics rather than by thermodynamics. Essential nutrient cycles are controlled largely by the metabolic processes of living organisms. For nonnutrient elements, scavenging by nonliving organic materials is much more important. Settling particles are reactive enough to adsorb and transport a large variety of elements to the bottom. Because bacteria continue to degrade this material, the concentrations of many elements increase with depth and along current flow lines.

Surface productivity shows strong regional variability. The vertical particle flux and the intensity of scavenging and release also vary by region. For geochemical purposes, satellite pictures of ocean productivity must be projected into the vertical dimension to appreciate the fact that strong lateral variations in reactivity occur (reactivity is the intensity of the chemical reactions that are driven by biological activity in the ocean water column). Vast areas, such as the subtropical gyres, are quite unreactive; these are surrounded by a coastal rim of high reactivity. Other zones of high reactivity correspond to areas of physical upwelling.

The combination of lateral and vertical transport and continuous reaction of particles suggests that the water column distribution of elements at a particular location may have little influence on local processes but, instead, reflects the integration of processes over various time scales and distances. The best example of this effect is the deep silica maximum found throughout the Indian and Pacific oceans. It results from strong upwelling and associated high productivity of siliceous plankton in relatively small areas at these oceans' northern boundaries, and subsequent vertical transport and dissolution of their siliceous tests at depth.

The flux of particles to the seafloor is apparently the most important mechanism by which elements are delivered to the sedimentary reservoir. However, many complex processes, primarily biological, can occur after initial deposition. Particles falling from above are the only source of nutrition for many bottom-dwelling organisms. Thus this material is ingested and excreted repeatedly by a variety of species and is also subject to continuous bacterial degradation, reducing its carbon content and destroying the functional groups responsible for scavenging reactive elements from the water column.

Sinks

The two most important properties of the ocean system that control the uptake of chemical species by the sediments and oceanic crust are its oxidation state and its temperature.

Chemical reactions in sediments involving oxidation and reduction depend on the amount of oxygen present, which in turn depends on metabolic activity and diffusion from the overlying water column through the pore fluids. Where metabolic processes exceed the oxygen supply through diffusion, the sediments become anaerobic. This condition creates diffusion gradients in the oxic-anoxic transition zone from above and below, affecting a range of chemical reactions. The transition zone rises through the sediment column as sediment accumulation progresses. Understanding and quantifying these processes are crucial for studies of global change because of their implications for interpreting the sedimentary record.

The character of the crustal sink for oceanic dissolved material changes with the temperature of the water-rock interactions. At high temperatures, the reaction environment is anoxic. Sulfide-forming elements are precipitated; elements that form insoluble oxides in the reduced state, such as uranium and chromium, are also precipitated. Soluble materials, such as boron and alkali compounds, are completely removed from the rocks. Magnesium is removed but calcium is released. At the very high temperatures (>400°C) associated with recent eruptions, phase separation can occur, producing a dilute aqueous phase and a residual brine. Subsequent mixing of these components appears to be responsible for the large variations in salinity observed in hydrothermal fluids. Details of this process are not understood. A major unknown is the mechanism responsible for maintaining the salinity and temperature of the vent fluids at a given site at stable levels over periods of years.

Low-temperature weathering of the oceanic crust appears to constitute a major sink for alkali compounds and is accompanied by extensive hydration of the rocks. When the crust is subducted, this chemically bound water, along with the elements it can transport, most likely is released and migrates. The water may accelerate melting and participate in the eruption process in volcanic arcs.

Marine Organic Substances

The biochemicals that fuel marine organisms are photosynthesized and then respired in the upper ocean on time scales of hours to days. Only about 20 percent of the photosynthetic product escapes from the sunlit surface ocean as sinking particles, and less than 0.5 percent is ultimately preserved in marine sediments. Living organisms comprise only about 1 percent of the organic matter in the ocean. The remaining organic matter is primarily a dilute solution (about 1 part per million) of "dissolved" macromolecules (i.e., material that passes through filters with a pore size of 0.5 micrometer). The turnover rate of this dissolved pool is now under discussion; the traditional view is that the pool turns over at a rate of thousands of years. The alternative view is that, because the pool of dissolved organic material contains excess carbon-14 relative to what is expected in thousand-year-old organic material, it must turn over more rapidly. Because of the challenges of isolating or directly characterizing this extremely dilute component of seawater, only about 20 percent of the organic molecules have been described.

A little over a decade ago, a novel suite of organic lipids was first reported in sediments from the Atlantic Ocean and the Black Sea. The component molecules have a linear sequence of 37 to 39 carbon atoms containing one to four double bonds, with an oxygen atom doubly bonded to the second or third carbon in the chain. These long-chain alkenones were found to be produced by the marine coccolithophorid algae *Emiliania huxleyi* and related species that are widely distributed in tropical and subtropical oceans. The same molecules were also discovered in sediments dating back to the Miocene (about 20 million years ago).

It was later demonstrated in the laboratory that the average number of double bonds (extent of unsaturation) in these alkenones of *E. huxleyi* and related algal species increased at lower culturing temperatures, apparently a chemical response to maintain membrane fluidity. Brassell et al. (1986) discovered that in natural deposits the average number of carbon double bonds in alkenones from Quaternary sediments of the northeast tropical Atlantic showed a strong inverse correlation, over the past 120,000 years, with the temperature of the near-surface ocean water as inferred from the stable oxygen isotopic composition of coexisting calcium carbonate shells of the planktonic foraminifera *Globerigerinoides sacculifer.* This observation suggests that the relative changes in water temperature at the ocean surface during at least the past 100,000 years could be inferred from the stratigraphic record of alkenone composition in the underlying sediments. Prahl and Wakeham (1987) calibrated the alkenone paleothermometer for *E. huxleyi* within ±0.5°C and they provided evidence against the idea of diagenetic alteration of the molecular temperature record in the marine water column.

The alkenone paleothermometer has potential applications beyond simple confirmation of stable oxygen isotopic records of sea surface temperatures. For example, alkenone measurements can be applied readily to bulk sediment samples. The alkenone paleothermometer thus ranks as one of the major contributions in the past decade of marine organic chemistry research to understanding paleoceanography and paleoclimatology.

The application of the alkenone paleothermometer was made possible by the recent development of gas chromatographic ratio mass spectrometers, instruments that measure the stable carbon isotopic compositions of individual organic molecule types separated during the rapid (approximately one hour) gas chromatographic analysis of complex organic mixtures.

Future Directions

Analytical Methods

The chemical processes occurring within the ocean reactor are kinetically controlled except in high-temperature regimes, where thermodynamic equilibria may be inferred. These kinetic processes are driven largely by organisms; they involve chemical reactions that are difficult to reproduce in laboratory experiments because of their complexity and variety. Thus, the general strategy in studying the marine geochemistry of the present ocean and its variations in the geologic past is to pose questions in which causes are inferred from measured distributions, that is, as an inverse problem. Variations in measured concentrations reflect changes in the relative importance of these causes. This inversion is constrained by different chemical properties of the elements of the periodic table, their valence states, their isotopes, and the compounds they form. It follows that this strategy requires the measurement of a vast array of chemical properties. Although technology development is required for measuring some of these properties, each of the elements and forms is not equally important diagnostically. Extraction of all the information useful in constraining the inversion is a prodigious analytical task.

Until recently, each available instrument could analyze only a few elements at the sensitivity, precision, and accuracy levels necessary for their concentration in natural samples. Thus no laboratory could perform more than a small fraction of possible measurements. Over the past 10 years, the sensitivity of instruments has increased vastly. Accurate and precise multielement analyses on single samples are now feasible, and multiple collector thermal ionization mass spectrometers have increased the sensitivity for a wide range of elements and isotopes. High-energy accelerator mass spectrometry allows the measurement of the cosmogenic radioisotopes in the study of a wide range of geochronological questions; it also allows exploitation of the unique properties of these isotopes in a variety of tracer studies. Plasma source mass spectrometry makes it possible to perform accurate multielement analyses on extremely small amounts of material. This technology eases measurement of refractory elements that, because of their low volatility or high ionization potential, are difficult to measure with conventional techniques.

Mass spectrometry for the measurement of $\delta^{18}O$, $\delta^{13}C$, and other light isotope systems are well established, as are methods for determining radiogenic isotopes. New developments in high-resolution thermal ionization mass spectrometry for the measurement of ^{230}Th, ^{232}Th, ^{234}U, and ^{238}U and the negative thermal ionization mass spectrometric measurement of $^{187}Os/^{186}Os$ have improved our capacity to use these isotopes in marine geochemical studies.

Improving Our Knowledge of Fluxes

Much more research needs to be done to quantify continental inputs to the oceanic reactor. An important adjunct to studies of fluxes will be long time-series measurements that will allow an estimation of variability of fluxes. Weathering processes are traditionally regarded separately from oceanography, but oceanic techniques are essential to trace the pathways by which material enters estuarine mixing zones through rivers, progresses across the shelf, and finally moves into the deep sea. For some elements (e.g., iron), delivery to the world ocean by this route is negligible because of their insolubility in seawater. Soluble elements pass through the coastal ocean with little loss. Research on this topic has great societal importance because chemical fluxes substantially alter global climate, coastal pollution, and possibly harmful algal blooms and fisheries production.

The strength of airborne transport of particles is known to vary widely with climatic conditions. Airborne transport is the one direct pathway between the continents and the surface waters overlying the deep ocean, and its importance as a supplier of micronutrients (e.g., iron and selenium) needs to be more firmly established. It is possible that the productivity of some areas of the ocean is controlled partially by the amount of airborne trace metals. This area of research is an active one.

Estimates of the hydrothermal flux range over a factor of five. The mechanisms responsible for the wide salinity variations and the temporal stability of the values at a given site are not understood. Both of these problems can be resolved only by systematic investigation of vent fluids from different sites and by development of additional tracers of both the subsurface reaction processes and the characteristic hydrothermal inputs to the global reactor.

Fluid inputs from the mid-ocean ridge flanks and from subduction zones are perhaps best studied by drilling and pore water sampling because the flow across the seafloor-water interface may be too diffuse for discrete sampling in the water column. Much improved down-hole sampling and measurement capabilities are required. Systematic sampling of representative ridge flanks and subduction zone complexes is needed, using the complete range of modern geophysical tools.

Understanding Redistribution and Removal in the Ocean

The general circulation of the global ocean has been relatively well described. From the geochemical point of view, much remains to be learned about the relative importance of the removal of elements at ocean boundaries versus in situ removal by settling particles. The spatial and temporal variability of processes controlling the vertical flux of elements needs to be characterized. The same is true for the evolution of the chemical properties of sinking particles traveling through the complex food web in the water column and on the seafloor. In the upper waters and thermocline, large horizontal variations in primary productivity and higher levels of food webs have been observed, but little is known about the lateral variability of deep-ocean ecosystems. The effects of ecosystems on the chemistry of particles passing through them are largely unknown. It is important to know whether there is a simple proportionality between surface productivity and the chemistry of the underlying water column or whether the particular faunal assemblages in the water column exercise a major role in controlling element concentrations.

The mechanisms of sediment interactions and diagenesis are well studied for the major constituents, nutrients, and oxygen; much more work is needed on the behavior of minor and trace constituents. Intensive research on the behavior of trace elements in the most reactive upper few meters of the ocean is also necessary. Descriptions of composition changes need to be developed for the various sediment types and environments through all phases from initial burial to subduction.

Reading the Record

Complete decipherment of the proxy record contained in the concentration distributions of trace elements and isotopes in sediments requires an understanding of the pathways of input and the mechanisms of redistribution, removal, and transformation of the elements studied. A given tracer may record a single aspect or some combination of these factors. Ideally, multiple tracers should be used as a check on internal consistency. Because only a small number of tracers are now available, much development work is required.

It is known that the continental inputs of a number of potential tracers are changed markedly by human influence, which makes estimates of their response to environmental changes difficult. River inputs are often strongly mediated by coastal processes and hence are sensitive to sea-level variations that change the size and character of the coastal ocean. Comparative studies of shelf-dominated systems (e.g., the Yangtze and Yukon rivers) with systems in which rivers discharge directly over deep waters (e.g., the Columbia and Congo rivers) may be informative.

The relative importance of physical and chemical redistribution processes and the mechanisms of sediment uptake must be established for each tracer; this will be difficult experimental work. Postdepositional redistribution processes must be characterized for the range of sedimentary environments. The establishment of reliable proxy records merits high priority because it is the most direct constraint on the modeled mechanisms of previous global changes in environmental processes.

DIRECTIONS FOR MARINE GEOLOGY AND GEOPHYSICS

Summary

The plate tectonic paradigm, first quantitatively described more than 25 years ago, provides an integrated physical and chemical framework for understanding the geological evolution of Earth. Marine geologists and geophysicists played a critical role in the development of this paradigm. By linking marine magnetic anomalies to geomagnetic reversals of Earth's magnetic field, marine geophysicists were able to confirm seafloor spreading and provide quantitative estimates of seafloor spreading rates. Through holes drilled by the Deep Sea Drilling Project, marine geologists were able to extend the geomagnetic reversal time scale back nearly 200 million years, providing a framework within which to reconstruct the past positions of the continents and the opening and closing of ocean basins.

Throughout most of the 1970s, the major emphasis in marine geology and geophysics was on large-scale kinematic descriptions of relative plate motions and their consequences for the geological evolution of ocean basins. However, by the 1980s, the focus of the field had shifted toward more process-oriented studies centered around understanding how oceanic crust and lithosphere are created, how these processes are related to the underlying mantle, and the consequences of seafloor spreading on ancient ocean circulation and climate. Four themes currently dominate research in marine geology and geophysics: (1) the formation of oceanic crust and lithosphere along mid-ocean ridges, and the associated volcanic, hydrothermal, and biological processes; (2) off-ridge processes and their relation to mantle convection; (3) the structure and tectonics of active and passive continental margins; and (4) the record of past climate change and ocean circulation preserved in marine sediments. In addition to these four themes, there is increasing interest in the study of coastal processes including sediment erosion and transport, and estuarine and delta sedimentation. Coastal processes are discussed elsewhere in this report.

In the 1990s, marine geologists and geophysicists will begin a major, decade-long study of the global mid-ocean ridge system through the Ridge Inter-Disciplinary Global Experiment (RIDGE) program. The long-term goal of this program is to obtain a sufficiently detailed spatial and temporal definition of the global mid-ocean ridge system to construct quantifiable, testable models of how the system works, including the complex interactions among the magmatic, tectonic, hydrothermal, and biological processes associated with crust formation. Among the goals that are achievable in the next decade are a *global* characterization of the structure and energy fluxes along the entire 50,000-kilometer-long mid-ocean ridge system and the establishment of a permanent seafloor observatory on an active ridge segment to investigate the scales of variability in tectonic, magmatic, hydrothermal, and biological processes associated with the formation of new oceanic crust.

The ancient ocean crust contains unique information about mantle convection and composition. An improved understanding of the chemical and isotopic record of mantle convection and the variation of melt production through time is likely in the next decade. Mapping crustal composition on an ocean basin scale will require hundreds of shallow holes to be drilled into ocean crust. Directly sampling the suboceanic mantle will require the development of new drilling technology beyond that presently available to the ocean drilling community. New seismic tomography techniques for imaging the Earth's mantle will allow marine geologists to begin to relate mantle convection processes to melt production rates, lithospheric stress and intraplate deformation, and the variation in chemical and isotopic composition of the crust. Vastly improved seismic images of the suboceanic mantle are possible if an array of seafloor seismic stations is established in the 1990s to augment the global digital seismic network.

Continental margins are the locus of lithospheric deformation, sediment accumulation, and substantial and chemically distinctive magmatism. Subduction and rifting processing at margins determine the size, shape, and distribution of continents and result in complex and dynamic interactions among oceanic crust, continental crust, and mantle systems. A basic description of the nature and evolution of many margins is available today, but understanding of the dynamics of margin development is still very limited. The development of new technology for probing the deeper structure of continental margins, and new conceptual advances in areas such as sequence stratigraphy and fault dynamics, provide an opportunity for the development of fundamental new insight into margin structure and evolution. What is needed is a coordinated, interdisciplinary research effort involving both land-based and sea-based research programs over the next decade.

Marine sediments provide an important record of geological processes including past global climates. For example, analysis of marine sediment cores has provided critical information on the importance of Earth's orbit in short-term climate change. Marine sediments also provide a record of global sea-level changes, sea surface and bottom water temperature variations, changes in ocean current patterns, the volume of water locked in polar ice caps, and the effects of a changing physical and chemical environment on the evolution of marine life. Through drilling and coring, especially in high-latitude regions, paleoceanographers are poised to make major advances in our understanding of the natural variability in global climate systems in the coming decade.

Introduction

The plate tectonic paradigm forms an integrated and linked physical and chemical framework for the flow of energy and mass through Earth (Figure 3-1). Radioactive decay of material within Earth's interior produces heat and creates a convective system that transports heat and material from deep within Earth to shallow levels. Upper mantle rocks partially melt, producing basaltic magma. Much of this melt is preferentially focused along the world-encircling mid-oceanic ridge, where oceanic crust is created. In time, the oceanic lithosphere (the oceanic crust and upper mantle) will be recycled into the mantle at convergent margins. The oceanic crust and some sediment are carried back into the mantle, and the crustal components dehydrate, pumping water and gases into the overlying mantle, causing partial melting and fractionation, and creating silica-rich rocks, ore bodies, and explosive volcanism along the overlying volcanic arc.

As oceanic crust ages and moves away from the ridge axis, it modifies Earth's environment. The chemistry of seawater is altered as the oceanic crust cools and exchanges elements with the seawater that circulates through it (see "Directions for Marine Geochemistry"). At convergent margins, some sediment is scraped off the subducting crustal plates, injecting fluids rich in dissolved constituents into the overlying ocean waters. Moreover, the aging oceanic lithosphere serves as a repository for sediments that

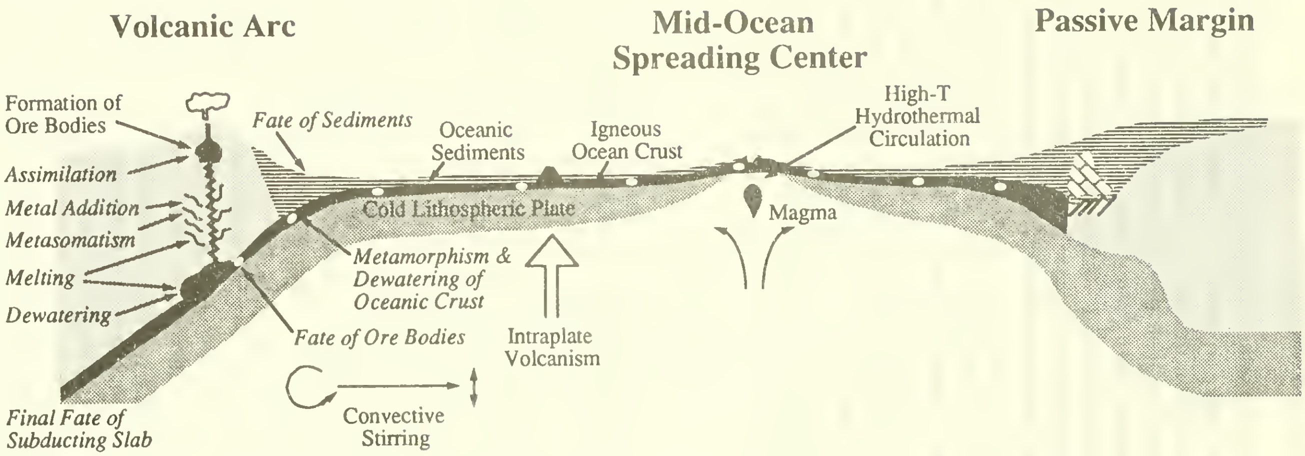


FIGURE 3-1 Cartoon of the solid Earth geochemical cycle showing some of the fluxes, processes that control the fluxes, and the sedimentary reservoirs that provide a record of these processes. Lithosphere is created at mid-ocean spreading centers from upwelling mantle material and is recycled into the mantle at subduction zones. This solid Earth geochemical cycle controls the flux of heat and mass from the Earth's mantle to the hydrosphere, biosphere, and atmosphere.

represent a coherent high-resolution continuous record of environmental changes on time scales from years to millions of years. Given the mobility of crustal plates, the geometry and location of ocean basins and continents have changed through time. This changing plate mosaic has had a profound effect on global sea level and on ocean and atmospheric circulation.

In essence, plate tectonics is the surface expression of a solid Earth geochemical cycle. An understanding of how this cycle has operated in time and space is a fundamental starting point for Earth systems research, and it unifies the field of marine geology and geophysics. The four principal elements of this research are (1) the oceanic ridge and lithosphere, (2) off-ridge processes, (3) ocean margins, and (4) ocean basin sediments.

Oceanic Ridge and Lithosphere

The global mid-ocean ridge is perhaps the most striking feature on the solid surface of our planet. Sections of the ridge extend along the floor of the world's ocean to a length in excess of 50,000 kilometers. The mid-ocean ridge dominates Earth's volcanic flux and creates an average of 20 cubic kilometers of new oceanic crust every year. Two-thirds of the annual heat loss from Earth's interior occurs through the generation and cooling of the oceanic lithosphere, partially by the circulation of seawater through fractures in the hot oceanic crust. This hydrothermal circulation facilitates a major chemical exchange between seawater and oceanic crustal rocks that acts as an important regulator of the chemistry of the ocean and of the volatile content of Earth's interior. The most stunning manifestations of this circulation are the high-temperature hydrothermal vents along the ridge axis.

Many discoveries of ridge phenomena have been made over the past decade, and a number of sophisticated technological tools have been developed for detailed investigation of the seafloor and the subsurface crust. High-temperature hydrothermal vents, for example, were discussed only as theoretical possibilities before their discovery in the Pacific in the late 1970s. High-resolution swath mapping and side-scan sonar imaging systems have only recently begun to provide information on the detailed morphology and structure of ridge systems. Multichannel seismic imaging techniques have advanced and thus have enabled marine geologists to begin imaging the magma chambers that lie below the ridge axis (Detrick et al., 1987). Much of the promise of this new technology remains to be realized. Detailed sampling and mapping of the mid-ocean ridge, for example, have been confined to only a small fraction of the total ridge length. The diversity of volcanic and tectonic processes manifested along the ridge axis, as a consequence, has not yet been fully defined. More fundamentally, the complex and linked processes of magmatism, hydrothermal circulation, development of vent ecosystems, and lithospheric evolution are only dimly understood. The dynamics of these processes have not yet been elucidated because of the lack of in situ observations of sufficient duration and diversity to determine the important interactions and time scales.

For a better understanding of mid-ocean ridge processes and their impacts on the chemical, physical, and biological evolution of the oceanic mantle, crust, and hydrosphere, specific aspects of the ridge system will require focused research efforts. Some are discussed below.

Mantle Flow, Melt Generation, and Magma Transport Beneath Mid-Ocean Ridges

Plate spreading and the generation of new oceanic crust and lithosphere along oceanic spreading centers involve a variety of complex and interrelated geodynamic processes: upwelling and horizontal divergence of the solid mantle beneath spreading centers, pressure-release melting of this upwelling mantle and segregation of the partial melt from the deforming solid matrix, the emplacement and solidification of melt at shallow depths to create the oceanic crust, and the cooling of the crust and mantle to form the oceanic lithosphere. These processes are still among the more poorly understood aspects of the seafloor spreading process. Two of the most important questions are (1) the pattern of mantle flow beneath mid-ocean ridges, and (2) the geometry of the melting region in the mantle and how melt migrates to the ridge axis. Simple plate-driven flow, due to viscous coupling of the asthenosphere to the separating lithospheric plates, predicts a simple two-dimensional upwelling pattern more than several hundred kilometers in width. Pressure-release melting of this upwelling mantle is thus expected to occur over a very broad region beneath mid-ocean ridges. One of the first-order paradoxes in our present understanding of mid-ocean ridge geodynamics is how partial melt formed over such broad regions beneath ridges migrates to the extremely narrow (1- to 5-kilometer-wide) zone of eruption observed at mid-ocean ridges. We also have only a very crude un-

PLATE 1 Average global sea level variability for 1987 and 1988. Data were obtained by the Geosat satellite altimeter. Figure provided by C. J. Koblinsky, NASA.

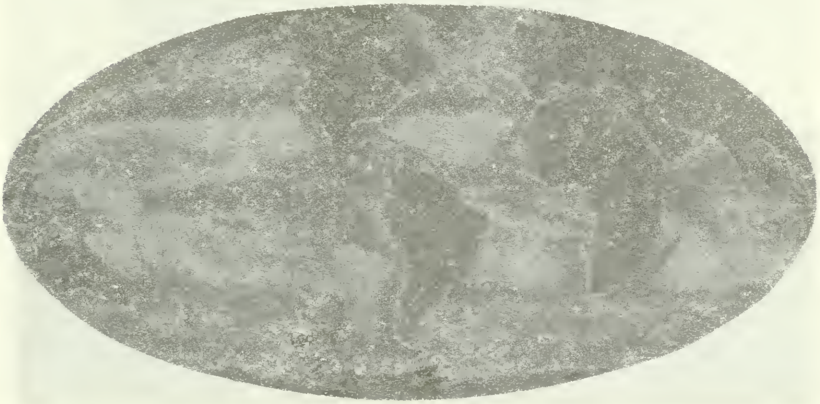


PLATE 2 Multiyear composite of global ocean pigment concentration (November 1978 to June 1986). Data were acquired by the Coastal Zone Color Scanner on the Nimbus-7 satellite. Purple and blue areas contained low concentrations of pigment in surface water and yellow and red areas indicate high concentrations of pigment. Figure provided by Gene Feldman, NASA.

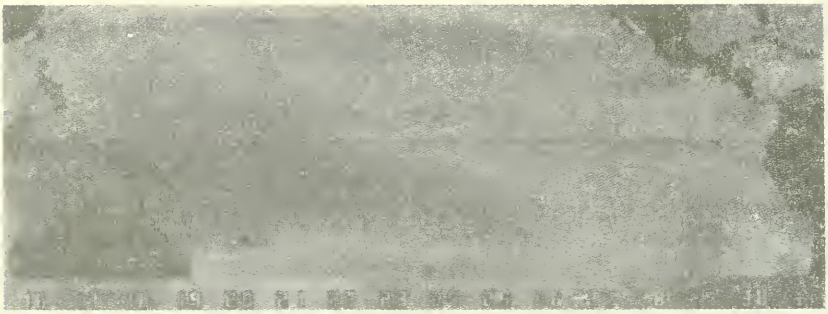


PLATE 3 Sea surface temperature during a non-El Niño year. The warm water is located in the western Pacific. The 29°C isotherm is located at 170°E. Satellite data processed and provided by Dr. Xiao-Hai Yan at the Center for Remote Sensing, University of Delaware.

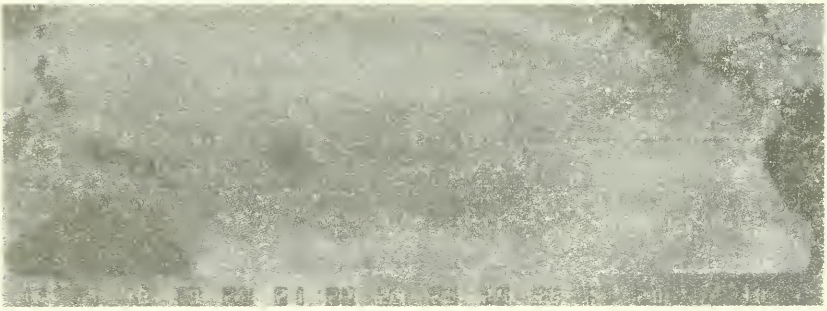


PLATE 4 Sea surface temperature during an El Niño year. The warm water extends to the central and eastern Pacific. The 29°C isotherm extends to 150°E. Satellite data processed and provided by Dr. Xiao-Hai Yan at the Center for Remote Sensing, University of Delaware.

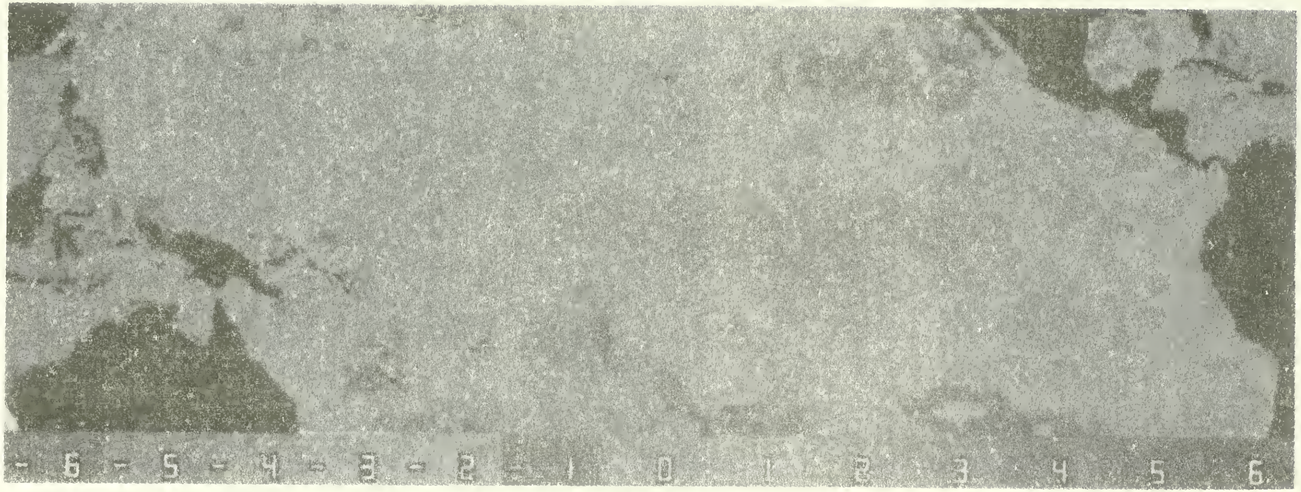


PLATE 5 Sea surface temperature difference between an El Niño year and a non-El Niño year. Satellite data processed and provided by Dr. Xiao-Hai Yan at the Center for Remote Sensing, University of Delaware.

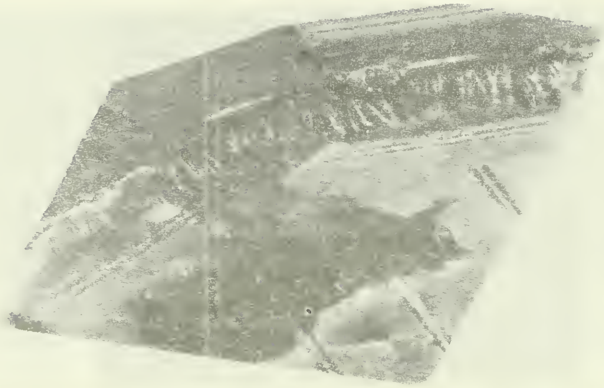


PLATE 6 Integration of GLORIA data with bathymetric data has proven extremely effective in visualizing seafloor geology. This photo shows a perspective view of a portion of the Florida Escarpment with the small ravines cut into it and the meandering channel running across the abyssal plain floor at the base of the escarpment. Photo courtesy of Dr. David Twichell, U.S. Geological Survey, Woods Hole, Massachusetts.

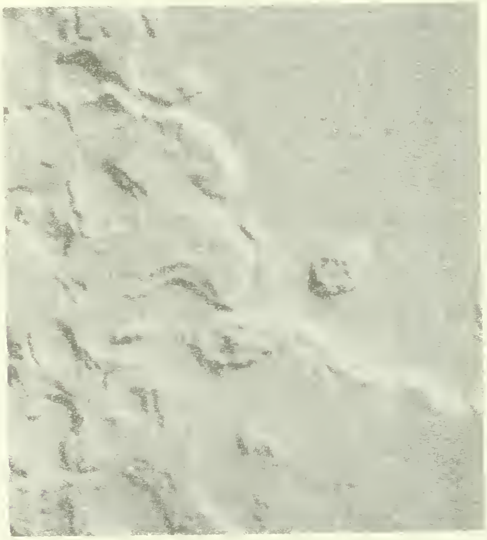


PLATE 7 Shaded relief image of Seabeam bathymetry along the Texas-Louisiana continental slope. Data collected by the NOAA National Ocean Survey. This image shows part of the Sigsbee Escarpment, several collapse basins north of the escarpment, and one salt diaper south of the escarpment. Area shown is approximately 50 by 60 nautical miles. Photo courtesy of Dr. David Twichell, U.S. Geological Survey, Woods Hole, Massachusetts.

derstanding of how this two-dimensional plate-driven flow develops into a more three-dimensional upwelling pattern along some ridges and how this flow affects, or is affected by, the observed segmentation of oceanic spreading centers.

By deploying an array of ocean bottom seismometers across a section of the mid-ocean ridge and recording a sufficient number of seismic events at different ranges and angles, it should be possible to improve the resolution of the seismic structure of the shallow mantle beneath a ridge crest. A major goal for the next decade is to carry out one or more of these studies on the mid-ocean ridge.

Processes That Transform Magma into Oceanic Crust

The transformation of magma into oceanic crust at spreading centers has fundamental implications for the mechanisms of heat and material transport from deep within Earth to the lithosphere, hydrosphere, and biosphere. The important processes that transform mantle melt into oceanic crust and the role of crustal chambers are poorly understood. The global distribution and physical properties of magma chambers at oceanic ridges and their temporal and spatial variability should be determined. Internal dynamics of magma chambers are important factors that must be understood, along with their effects on the structure and composition of the crust, the transfer of heat from the magma chamber, and the physical and chemical processes occurring at the interface between the magma chamber and the overlying region of seawater circulation.

Processes That Control the Segmentation and Episodicity of Lithospheric Accretion

The use of new technology, such as satellites, swath mapping, and side-scan sonar, has revealed that the global rift system is segmented and that the pattern of segmentation varies temporally and spatially. It is essential to understand the physical processes controlling segmentation and its temporal and spatial variation as well as the processes causing episodic production along individual segments and their boundary zones. Melt migration and eruption, faulting, fissuring, and stretching must also be better understood so that the individual processes and their possible interactions can be studied and interpreted.

Physical, Chemical, and Biological Processes Involved in Interactions Between Circulating Seawater and the Lithosphere

Hydrothermal plumes that issue from seafloor vents link the oceanic lithosphere, hydrosphere, and biosphere through complex physical, chemical, and biological interactions (Rona et al., 1986). A detailed understanding of the individual processes that constitute a hydrothermal system will provide insight into many problems in biological, chemical, geological, and physical oceanography. Although present research on seafloor hydrothermal circulation has begun to address a few of these problems, new approaches and a more focused effort will be required to achieve an interdisciplinary view.

Distribution and Intensity of Mid-Ocean Hydrothermal Venting

The character of hydrothermal plumes is determined by both crustal processes and the oceanic environment. Changes in the plume can reflect events with diverse spatial and temporal scales, such as magma chamber evolution, changes in the subsurface hydrothermal plumbing, and shifting bottom currents. To understand these complex interactions, we must study hydrothermal plumes over a wide range of scales in time and space: from the scale of the individual vent plume fluctuating over a period of seconds up to the 1,000-kilometer scale of the large ocean-basin plumes estimated to contain the integrated output from 100 years of hydrothermal venting. An important new research direction is to move from the realm of general observation to the quantification of rates and processes in hydrothermal plumes.

In summary, an improved understanding of the mid-ocean ridge system will require focused efforts. Present technologies are relatively well developed for establishing the occurrence of spatial variations within the ridge system, but obtaining observations of temporal change will be challenging. Global-scale reconnaissance surveys can help in selecting sites for more focused regional studies in which coordinated experiments would involve a range of long-term measurements. A common requirement of many of the recommended studies is accurate age information on time scales between a decade and a million years. Innovative approaches to dating hydrothermal fluids, rocks, and biological materials will be necessary to meet this requirement.

Off-Ridge Processes

Off-ridge processes can be studied to determine how Earth functioned in the past and whether there are additional temporal variability and forcing functions that will not be discovered by studying the geological present. The seafloor contains a record of the creation of the oceanic lithosphere. In addition, important questions concern changes in the oceanic crust as it ages. The older oceanic crust also contains information concerning mantle convection and composition. Several important investigative themes can be identified.

Chemical and Isotopic Record of Mantle Convection

Because the mantle is overlain by the crust, it is not possible at present to sample the suboceanic mantle directly, except in tectonically anomalous areas (e.g., oceanic fracture zones). The basalts that are derived from the mantle, however, are indirect mantle samples that have been modified by partial melting and partial crystallization. Because the oceanic crust is thin and its composition is similar to the magma, and because the spreading center provides a relatively permeable and free pathway to the surface, ocean ridges are the sites where the magma is least modified. Thus ocean ridge basalts typically provide the least adulterated record of mantle composition and temperature. Mapping crustal composition can provide quantitative information about the size, distribution, and composition of mantle reservoirs and the efficiency of convective stirring. This information is a record and an opportunity to map indirectly the composition and temperature of the mantle.

Variation of Melt Production (Convective Vigor) Through Time

There is strong evidence that plate separation rates and basaltic magma production rates along ridges and within plates are not constant. For example, a 50 to 75 percent increase in the rate of formation of oceanic crust and a doubling in the production rate of basaltic magmas between 120 and 80 million years ago (Figure 3-2; Larson, 1991) has been documented. The changes may be due to a large mantle-derived super plume that may have lifted off the core-mantle boundary and have been responsible for increased seafloor spreading and large-scale oceanic plateau production (e.g., Ontong Java and Kerguelen plateaus). It has been suggested that the super

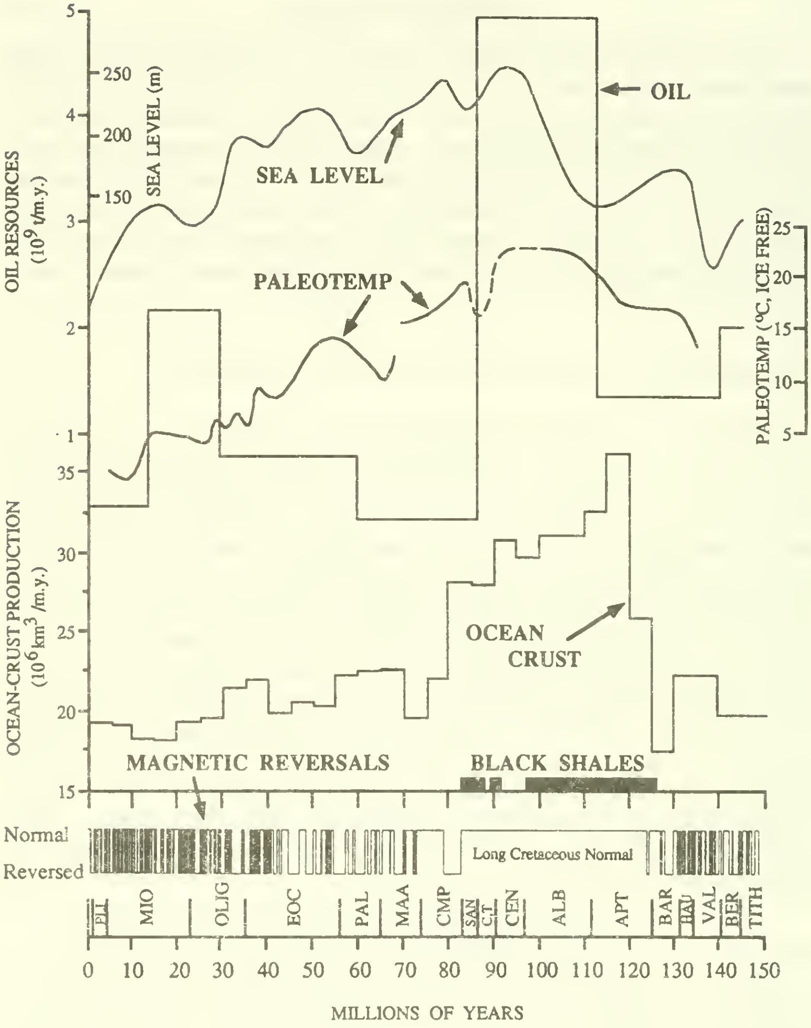


FIGURE 3-2 Combined plot of magmatic reversal stratigraphy; world crustal production; high-latitude, sea surface paleotemperatures; long-term eustatic sea level; times of black shale deposition; and world oil resources plotted on the geologic time scale. Note that increased volcanic activity in the Cretaceous is associated with eustatic sea levels, high sea surface temperatures, and black shale production. Thus, this may be a link between mantle processes (volcanism) and global climate. (Compiled from a variety of sources; Larson, 1991.)

plume had major geological consequences, including considerable increases in eustatic sea level, paleotemperature, oil generation, black shale deposition, and species diversification of phytoplankton and zooplankton. Such an event has profound implications for our understanding of mantle dynamics, oceanic plateau formation, and global environmental change.

Structure and Composition of Oceanic Crust

An understanding of crust formation cannot be achieved in the absence of better knowledge of the composition of the total ocean crust. This information would allow solution of a host of long-standing controversies, including the relationship between crustal structure and spreading rate, the origin of the seismically defined stratigraphy of the oceanic crust, the total magnetization of the crust and how it is distributed with depth, and the depth and nature of hydrothermal interaction in the crust.

Knowledge of Stresses Acting on Oceanic Lithosphere and Intraplate Deformation

The observational basis for plate motions is well established, but the relative importance of the forces (ridge-push, trench-pull, and plate-drag) that act on the plates and cause them to move is unresolved. In addition, the stresses that act upon the oceanic lithosphere at or near plate boundaries are poorly understood. Determining the stresses required to create these structures is key to understanding the tectonics of these environments (Zoback et al., 1985).

Ocean Margins

Continental margins are a principal site of lithospheric deformation, sediment accumulation, and mass flux on Earth and the site of substantial and chemically distinctive magmatism. Understanding their nature and origin will provide knowledge of the history of the ocean basins, and because the margins are progressively incorporated into the continental mass by plate interactions, the knowledge is also essential to our understanding of the mechanisms of continental evolution. In the next several years, the opportunity exists for researchers to develop a fundamentally new understanding of margins, a leap that may parallel that brought about by the plate tectonic revolution some 25 years ago.

A basic description of the nature and evolution of many continental margins is available today. However, understanding of the dynamics of margin development has not grown at the same rate. Knowledge of continental margin structure and motion has progressed, but understanding of the margins is limited by the need to understand the basic physical processes that accompany margin formation. Continental margins research must embrace a unified approach that emphasizes the important role of process-oriented interdisciplinary programs. Further, margins cross the shoreline, and such efforts will further enhance the developing synergism with Earth scientists involved in land and ocean research.

Fault Dynamics and Lithospheric Deformation

Any approach to the problems associated with lithospheric deformation demands the use of many tools. A wide-ranging field-mapping program is needed specifically to establish the link between surface deformation and deformation in the lower crust. For example, the configuration of large faults at depth in the crust and the structural fabric associated with distributed deformation in the upper mantle must be established by large-scale seismic imaging and tomographic techniques. Laboratory studies are also essential to establishing the constitutive laws for frictional behavior of both large deformation zones and discrete fault zones and defining their variability with strain, strain rate, and fluid content. Models of fluid flow in deforming porous media and methods to relate the models to observable quantities for field observation are required.

Mantle Dynamics and Extension

Understanding the interaction between mantle processes and lithospheric extension will require a focused multidisciplinary effort. Wide-ranging field-mapping programs must be designed to establish specific links between surface deformation and deformation in the lower crust. Large geophysical experiments will be needed to define the modern structure of rifts and margins and the thermal and dynamic state of mantle beneath young, presently active rifts. This work must be combined with geological mapping and thorough geochemical studies of magmatic systems to determine the nature of mantle sources, the history of melting, and fractionation. The development of shear-wave techniques and electromagnetic methods to increase their sensitivity to the detection of fluids will be particularly relevant.

Recycling

Mass flux studies needed to understand convergent margins as dynamic systems will involve integrated field, analytical, experimental, and theoretical studies that draw from geochemistry, petrology, and geophysics. Such projects require marine as well as land-based studies and careful integration of results from the two. Sampling must include fluids, melts, sediments, crust, and gases from the entire subduction zone, the subducting plate to the back-arc zone. Theoretical and experimental studies are an essential addition to these geochemical and geophysical programs. Existing studies have related only to isolated aspects of mass fluxes at convergent margins. However, the results of these studies can be used in conjunction with samples from existing and planned Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) holes drilled offshore of various trenches to formulate an integrated, multidisciplinary plan for studying these complex systems.

Ocean Basin Sediments

Marine sediments provide important records for important Earth processes. For example, marine sediments furnish a history of regional and global volcanic activity, a record of the long-term changes in Earth's magnetic field, and a tool for studying large-scale tectonic processes, such as continental accretion and rifting. An active area of research is the study of past global climates.

Evidence of global environmental change comes from the paleoclimate record, which is the only long-term record available. The paleoceanographic record provides information necessary to understand environmental changes (see "Directions for Marine Geochemistry"). The paleoceanographic record also places observations of the present ocean in a historical context of long-term environmental variability. It affords a unique opportunity to test our understanding of the climate system as represented by numerical models of the ocean-atmosphere system. If models of the present ocean are capable of hindcasting oceanographic conditions, then we should have more confidence in their predictive capability. Whereas satellites provide a global means to observe the ocean surface, ocean sediments and the proxy indicators of oceanographic processes defined by paleoceanographers provide a global array of sensors to monitor processes within the ocean over long time scales. However, we must understand the relationships between these proxy data and modern processes to use this global information effectively.

With sampling resolution ranging from annual to interannual to millions of years, study of the marine sediment record allows the study of past climates on a wide range of time scales. Six specific research themes need to be addressed to improve significantly our understanding of global climate change and its effects; they are described briefly below.

Short-Term Spatial and Temporal Variability in the Climate System

It is desirable to characterize the natural variability in the climate system on annual and interannual time scales over spans of thousands of years. With this information, the significance of instrumentally observed climate changes can be assessed and the variations related to human influences. Marine sediment records already analyzed provide a qualitative, although spatially limited, picture of variability over the past 1,000 years, which appear to have contained several intervals of colder than normal climate (e.g., the Little Ice Age) as well as possible warmer time intervals (e.g., the Medieval Warm Period). Information on the magnitude and frequency of short-term variability should make possible a substantially improved assessment of the degree to which present trends are associated with increasing greenhouse gas influences.

Geological Record of the Carbon System

The objective is to identify and understand the role of the carbon system in past climatic change by isolating the response of global climate to natural changes in atmospheric carbon dioxide and other greenhouse gases. Studies of ice cores spanning the past 160,000 years now provide direct evidence that atmospheric carbon dioxide has changed over a large range (180 to 300 parts per million) during this period. Geologic evidence for the more remote geologic past suggests that atmospheric carbon dioxide may have been as high as four to eight times its present level. Knowledge of these large atmospheric carbon dioxide changes on geologic time scales presents an opportunity to understand global climate change and to test model estimates. For the period of ice core records, there is a well-documented forcing of climate changes by the distribution of solar radiation owing to Earth's orbital parameters. The response of climate to these forcing functions can be quantified through study of the geologic records. Thus the task is to document the interaction between the oceanic and terrestrial carbon cycle and atmospheric carbon dioxide as well as the pattern of climate change.

Instabilities in Ocean-Atmosphere Circulation in Earth History

Evidence strongly suggests that ocean circulation is sensitive to climate change, and changes in ocean circulation in turn influence the nature of the climate equilibrium (Kennett, 1977). The geologic record provides evidence for rapid, short-term transitions in deep-water circulation, associated changes in surface circulation and upwelling, climate changes during recent geologic history, and several abrupt reorganizations in ocean circulation over the past 60 million years. The ability to characterize the transitions in ocean circulation and to define, independently, the nature of the changes in the atmosphere will provide the means to describe case studies of the links between the ocean and the atmosphere.

Historical evidence confirms ocean response times on the order of decades, even for deep water, and a close link among climate and moisture fluxes, salinity, and deep-water circulation. Modeling studies indicate the potential for abrupt transitions between modes of deep-water circulation associated with little or no change in external forcing or with implied changes in surface moisture fluxes.

Episodes of Moderate to Extreme Warmth

Several intervals during the past 100 million years were significantly warmer than the present. Proxy evidence and the results of preliminary global circulation model sensitivity studies suggest carbon dioxide levels significantly higher than today's as the likely explanation of the global warmth during most of these episodes.

Geological Record of Global Sea-Level Change

The geological record contains widespread stratigraphic evidence of sea-level rises and falls (Shackelton, 1987), but further studies are needed to determine the magnitudes, rates, and causes of sea-level changes. Before the mechanisms of sea-level change can be addressed meaningfully, better estimates of the magnitude and rates of sea-level changes during the preglacial and glacial past must be obtained. It is especially important to determine upper limits to the rate at which the sea level can rise. The constraints provided by better-magnitude estimates could eliminate several postulated causes of sea-level change and help focus on the most relevant possibilities.

Effects of a Changing Physical-Chemical State on the Evolution of Marine Life

The fossil record preserved in the ocean is the best source of information on evolutionary dynamics, as well as a powerful tool in forecasting the biological effects of global change. It provides an exceptionally detailed picture of the distributions of fossil species and the climatic conditions in which they lived. Many extinct marine fossils have living counterparts that can be studied for knowledge of the ecology and genetics of extinct species.

Were organisms able to acclimate to the new environmental conditions and, if so, how? The biological effects of extreme shocks to the biosphere can also be examined, such as that imparted by the asteroid impact with Earth at the close of the Cretaceous. These events permit us to evaluate both how organisms respond to the threat of extinction and how survivors set about repopulating the vacated environment. Many of these events can also be studied in the terrestrial fossil record. However, the higher resolution of the oceanic record permits a far more complete analysis of the forces that underlie evolutionary processes on a global scale than can ever be accomplished by using terrestrial organisms. This resolution permits us to evaluate the role of climate change as a driving force behind the production of new species, the extinction of existing species, and geographic shifts in populations. We can forecast the biological consequences of human-caused changes in the environment by examining similar events in the fossil record.

Research Approaches

Study of oceanic crust and sediments has been aided over the past 30 years by a number of new techniques, whose application will continue to yield information about the seafloor, a region of Earth that still remains largely unknown. Rock and sediment cores obtained through the DSDP/ODP have provided glimpses of the structure, composition, and the processes that formed these materials. Continued systematic drilling will be required to obtain a complete picture of the structure of the ocean crust and particularly the chemical composition and hydrothermal alteration processes. Drilling also allows geophysical and geochemical instruments to be placed within the drill holes to measure temperature, chemical fluxes, crustal strain, and other variables important for understanding geological, geochemical, and geophysical processes.

The technique of seismic tomography began when it was learned that by studying the propagation of seismic waves, both in terms of speed and path, through the Earth, features of Earth's structure could be discerned. Later, explosives and noise generated by "air guns" were used to generate sound that can be transmitted some distance into the seafloor and reflected back to acoustic receivers. These techniques have been used to gain a more detailed picture of the upper seafloor, particularly the sediment layer overlying the crust. The newest seismic technique has been to drill holes deep into the seafloor, placing acoustic sources in some holes and receivers in others, to produce a horizontal seismic tomograph of the intervening sediments and crust.

These methods provide a snapshot of structure and composition from which processes and fluxes may be inferred. As with other oceanographic disciplines, the importance of time-series observations for observing dynamic processes is critical. Scientists that study marine geology and geophysics will increasingly use time-series measurements of changing features, through repeat cruises, rapid-response measurement techniques, and particularly sensors moored on the seafloor. The area of fluxes is one in which chemical oceanography and marine geology and geophysics interact, because measurement of benthic chemical fluxes is important for both fields. Finally, the concept of "seafloor observatories" is being implemented through the RIDGE program and through research sponsored by the Office of Naval Research. These "laboratories" are actually areas of the seafloor where repeated intensive observations are made. For example, ONR has designated sites on the Mid-Atlantic Ridge (a slow-spreading ridge) and the East Pacific Rise (a fast-spreading ridge) as natural laboratories for comparative studies.

DIRECTIONS FOR BIOLOGICAL OCEANOGRAPHY

Summary

In the next decade, biological oceanography will emphasize the effects of ecosystems on global cycles of important elements, such as carbon, nitrogen, and oxygen, and conversely the effects of global environmental changes on marine ecosystems. Of timely interest are climate change and population dynamics of marine organisms. In addition to climate change that may be accelerated by carbon dioxide and other greenhouse gas emissions, overfishing, eutrophication, introduced species, and other anthropogenic changes affect marine populations, although impacts vary regionally.

The complexity of biological systems and their variability in both time and space pose practical problems for designing programs and setting research priorities. Potentially important approaches include both studies focused on regions or times of the year with clearly distinguishable food-web structures and intensive examination of areas where geochemical measurements have identified inconsistencies or contradictions. There is also an urgent need to initiate and strengthen long time-series studies of the biology and chemistry of key oceanographic regimes. In addition, concerted effort must be applied to increasing understanding of the basic ecology, physiology, and molecular biology of key marine species.

For the foreseeable future, biological oceanographers will need ships to collect seawater, sediments, and organisms and to prepare and process samples at sea. Thus oceanographic vessels will remain the primary facility for advancing basic knowledge of marine ecosystems. However, the use of other technologies and approaches could lead to important breakthroughs. They include satellite and aircraft remote sensing; numerical modeling; molecular biological techniques; optical, acoustical, and sample collection instrumentation and in situ data acquisition systems, including bottom landers; and remotely operated vehicles.

Introduction

Studying marine communities is difficult without an understanding of their associated physical, geological, and chemical environments. It is likely that biological oceanographers will strengthen interdisciplinary collaboration in the 1990s to include more atmospheric chemists, meteorologists, sedimentologists, paleontologists, and other Earth scientists. At the same time, advances in biological oceanography will contribute information critical to studies in chemical oceanography and related disciplines. The ocean is a biochemical system, and the biotic and abiotic components of seawater coevolved, resulting in a distribution of elements in the world's ocean that is dictated by biological processes in the sunlit surface waters.

Biological oceanographers study the regulation of plant, animal, and bacterial production; the mechanisms affecting the way production is partitioned among trophic levels and individual species; and the dynamics of marine populations. They use various approaches to study these phenomena. Some biological oceanographers measure concentrations of carbon, nitrogen, calories, and other basic constituents of life and the rates at which they are transferred through the food web and to the seafloor as sinking particles. Others explore the physiology, behavior, genetic diversity, and abundance of individuals within populations and use this knowledge to develop conceptual models of the nature and regulation of marine communities. In recent years, molecular biology tools have contributed to these measurements. Research in the next 10 years will emphasize how biota affect global cycles of carbon, nitrogen, phosphorus, oxygen, and other key elements and, conversely, how climate and other ocean environment changes affect marine ecosystems. During the 1990s and beyond, studies of marine ecosystems are likely to be central to resolving controversies surrounding the key issues of global change.

There is general agreement that the ocean is a significant sink in the global carbon cycle (and related cycles of nitrogen, phosphorus, silicon, and other biologically important elements) and thus is an important modulator of the greenhouse effect caused by the buildup of atmospheric carbon dioxide. Carbon dioxide in the surface mixed layer of the ocean is generally within 30 percent of saturation, whereas it is supersaturated in the deep ocean by as much as 300 percent with respect to the present atmospheric carbon dioxide level. The concentration gradient is maintained by the "biological pump" in the surface waters, which through biological fixation, packaging, and transfer results in a net downward flow of carbon to the deep sea. The ocean is a carbon sink because some of the organic matter synthesized by organisms in the sunlit upper ocean (the euphotic zone) settles to the seafloor, and some small fraction of that reaching the seafloor is eventually buried in marine sediments, where it may remain for millions of years. Annual carbon burial in marine sediments is 0.5×10^{15}

grams globally making this process the largest biotic sink of the global carbon cycle (Moore and Bolin, 1986).

One of the major uncertainties in the models of the global carbon cycle is the role of marine organisms in the ocean carbon budget. During the spring bloom in the North Atlantic, the air-sea carbon dioxide flux is strongly controlled by biological activity. However, the comparative magnitude of the ocean and terrestrial sinks of carbon is in dispute (Tans et al., 1990), owing primarily to lack of knowledge about air-sea gas exchange rates, the variability of carbon dioxide saturation of surface waters, and the effects of food webs on the production, reoxidation, sedimentation, and burial of carbon.

The rate at which dissolved or particulate matter passes through the horizontal plane at any particular depth in the ocean is called vertical flux, whereas lateral flux refers to flux through a vertical plane. In the ocean, the vertical flux of organic material (as well as the lateral flux of organic material between estuaries and waters above continental shelves and between shelf and oceanic waters) and its burial rate in ocean sediments are not simple linear functions of primary production. The structures of marine food webs (the number and type of organisms at various feeding levels and the feeding relationships among the organisms) in the euphotic zone, in mid waters, deep waters, and at the seafloor are key variables affecting vertical and lateral fluxes of biologically important elements.

As indicated above, marine food webs affect global biogeochemical cycles, and marine populations, in turn, are affected by changes in global climate and human-induced changes in ocean environments. Some of the best examples of climate effects on marine organisms come from European fisheries, for which long time series exist for fish catch and abundance in relation to key physical and biological variables. An extraordinary event occurred during the 1960s in the North Sea, where the abundance of codlike fish exploded as the herring population declined. This major change probably occurred in response to a period of cooling that decreased the abundance of certain zooplankton species during the time of the year when young herring require zooplankton as food (Cushing, 1982). The impact of El Niño on South American anchoveta populations is another well-known example.

Human activities also affect marine populations, particularly in estuarine and coastal waters, although anthropogenic effects are difficult to distinguish from highly variable natural cycles. Of particular concern are the long-term effects of nutrient enrichment (eutrophication) resulting from altered land use, and waste disposal as a reason for the low oxygen concentrations on continental shelves. An additional concern is the deliberate or accidental transport of species from one ocean to another by shipping or other activities, leading to outbreaks of the introduced species. Documenting the causes and effects of changes in marine populations is difficult, but new techniques and approaches will make this research possible in the future.

Effects of the Food Web on Global Biogeochemical Cycles

Phytoplankton, macroalgae, and sea grasses use energy derived from sunlight to incorporate inorganic carbon, nitrogen, phosphorus, and other elements into organic molecules that are the building blocks of life and sources of energy for nonphotosynthetic organisms that consume these plants. Some bacteria also synthesize organic matter using chemical energy (chemosynthesis) rather than sunlight as a primary energy source. In the ocean, most organic carbon produced by photosynthesis and chemosynthesis is ingested by zooplankton and higher animals, oxidized for energy, and ultimately respired as carbon dioxide in the upper few hundred meters of the water column. At the same time, nutrient elements, such as nitrogen, phosphorus, and some trace metals, are recycled and reused by phytoplankton. A variable fraction of organic matter is not recycled in surface waters; instead, it settles out of the upper ocean layers, thereby contributing to vertical fluxes. Thus fluxes of carbon, nitrogen, oxygen, phosphorus, sulfur, and other biologically important elements are controlled by food-web processes. A major research theme for the 1990s will be to describe the effects and possible controls that food-web structure and function have on fluxes from the euphotic zone to middepth and deep waters, to the ocean sediments, and into the geological record.

Episodic Export of Material from the Surface

The simplest description of the effects of marine food webs on vertical flux involves only the size and species of phytoplankton and whether the phytoplankton sink before being ingested. For example, the spring diatom bloom in the North Atlantic is thought to sink without significant predation, whereas where cyanobacteria are the dominant primary producers, sinking of organic material from the upper ocean is largely mediated by food-web processes.

In the latter case, vertical flux is small, mainly because of the number of steps in the cyanobacteria-based food webs, which lead to more recycling. In either case, the importance of the downward fluxes to the biota is that food resources are no longer available to the community from which they exit but seem to fuel successively deeper communities.

Most particles in the ocean are small and sink slowly. Particles that account for most of the transfer of material to the seafloor are the rarer, large particles that have both high mass and high sinking rates. They include the fecal pellets produced by large zooplankton, large aggregates of detritus and plant debris (marine snow), and living organisms. Zooplankton can increase vertical flux by repackaging and concentrating organic matter from small, slowly sinking phytoplankton and microorganisms into fecal pellets and mucous feeding structures that sink much faster than individual particles. Sinking flux varies by an order of magnitude among food webs. Food webs dominated by large zooplankton consumers may export a much greater percentage of consumed primary production than food webs in which phytoplankton are initially consumed by smaller protozoans and zooplankton, owing to the relative sizes and sinking rates of fecal pellets. Episodic zooplankton swarms could dominate the long-term average export of organic matter from surface ocean communities, but such swarms are often missed by short-term studies.

The activities of marine animals in breaking apart and consuming large aggregates on their way to the seafloor may also be significant, and as yet poorly quantified, factors in controlling particle flux. Many of these particles are consumed by animals as they sink and are converted into smaller fecal pellets, new animal growth, respired carbon dioxide, and dissolved organic matter.

Dissolved Organic Material

The measurement of dissolved organic material (DOM) is also of great interest to biological oceanographers and is an area of overlap between the disciplines of biological and chemical oceanography. The size, average age, and biological availability of the DOM pool are controversial, but the pool could be significant in global fluxes of carbon, nitrogen, and other biologically important elements. Furthermore, a major unresolved question is the degree to which DOM provides nutrition for the ubiquitous microbial community, which may use organic carbon at 10 to 40 percent of the rate at which phytoplankton use it.

Benthos

Deep-sea benthic organisms receive a slow nonseasonal rain of fecal pellets and dead organisms. Recent studies in the North Atlantic show that additional large pulses of organic particles arrive at the bottom within weeks to months following the spring phytoplankton bloom, probably accelerated by formation of marine snow particles. A complementary study in the same general area indicated that benthic organisms grow faster than previously believed, with maximum growth rates following the annual deposition of phytoplankton detritus from the spring bloom (Lampitt, 1990). An open question is the extent to which benthic organisms rely on these episodes of rich input. Certain large animals may metabolically cache food resources.

Ocean Margins

The role of coastal areas in global ocean carbon and nutrient cycles is controversial. Several issues remain, such as the percentage of seasonal and annual coastal production that is exported to the deep sea, the percentage of global productivity that takes place in the coastal ocean, and the extent to which the coastal ocean functions as a net carbon sink because of the massive inputs of nutrients. Interdisciplinary studies will be required to resolve the controversies regarding lateral exchanges between estuaries and the coastal ocean, and between coastal and deeper waters. This point is developed further in "Directions for Coastal Ocean Processes."

Biology of Hydrothermal Vent and Hydrocarbon Seep Habitats

Most oceanic food webs are based on photosynthetic productivity occurring in the upper regions of the ocean. A little more than a decade ago, it was discovered that dense bacterial and animal communities, which rely largely on in situ chemosynthetic activity, thrive at deep-sea hydrothermal vents and at hydrocarbon seep zones. Carbon fixation in these habitats is driven by highly reduced substances, such as hydrogen sulfide, that are exploited by both free-living bacteria and bacteria living within animal tissues.

The role of deep-sea hydrothermal vent systems in generating and dispersing fixed carbon is an area of active study. Although it is unlikely that carbon fixation at the hydrothermal vents is a major factor in total global carbon fixation, carbon fixation in the deep sea deserves study because of its uniqueness. Characterization of the global extent of these systems, the rates at which their free-living and symbiotic bacteria fix carbon dioxide, and the extent to which organic materials at vents are distributed to other regions of the oceans will be key areas of research for the next decade. Beyond understanding the biogeochemical role of these communities, studies of vent communities will give insight into the evolution and functioning of nutritious and detoxifying mutualism among organisms. Support for this work has a broad international base, such as through the RIDGE program, which supports multidisciplinary investigations of the biology, geochemistry, and geophysics of mid-ocean ridge-crest systems.

Study of these diverse ecosystems in which chemosynthetic processes replace or complement photosynthetic productivity is necessary to understand the complex nature of marine food webs and the full suite of exchanges and transformations that constitute the global carbon cycle.

Effects of Climate Change on Populations of Marine Organisms

The characteristics of a region that determine its suitability for any given organism include not only the availability of food and the abundance of predators but also the dynamic physical features (mixing and circulation) of the local environment that influence the success of recruitment, efficiency of feeding, and susceptibility of organisms to predation. Global change could affect oceanic animal populations by changing physical processes of significance to the planktonic organisms. At present, it is not possible to predict definitively the impacts of global change on the physical parameters of the ocean and the atmosphere. However, the effects of climate change can be partly anticipated by examining similar effects on shorter time scales, such as seasonal freshwater pulses, El Niños, and other infrequent oceanographic phenomena. Three examples illustrate how global climate change could affect the physical features and processes of the sea that influence the abundance, distribution, and production of marine planktonic animals.

High-latitude marine ecosystems may be more susceptible to global change than low-latitude marine ecosystems. If precipitation patterns change as estimated and global warming triggers the rapid melting of previously persistent ice fields and the retreat of glaciers, the volume of fresh water that enters polar waters (e.g., the Gulf of Alaska) is likely to increase substantially. The input of fresh water can be critical to coastal currents, as seen by the effects of the Mississippi and St. Lawrence rivers. Changes in precipitation (temporal and spatial) and the amount of ice melt could shift the direction and change the magnitude of coastal currents. Such physical changes will affect fish populations by affecting transport of eggs and larvae.

The effects of El Niño events on eastern boundary current ecosystems in the Pacific Ocean could serve as a model of the possible effects of global warming (McGowan, 1990) in terms of decreased primary and secondary production. In addition, an increased temperature differential between land and ocean could enhance coastal winds and hence wind-induced transport of surface water away from the shore, reducing the reproductive success of species that spawn offshore but rely on coastal habitats later in their life cycles. Stronger winds would also increase turbulence in the surface mixed layer, dispersing patches of planktonic food, and thereby making the food less available for fish.

The third example involves the impacts of a changing sea level. If sea level rises at a rate of 1 to 3 millimeters per year over the coming 50 to 100 years, profound impacts on nearshore habitats would result. In areas with broad, flat coastal plains, the width of the inner continental shelf may be expected to increase greatly. This change would wipe out many coastal habitats. In addition, distribution of the wave energy over a wider continental shelf may substantially modify the transport of planktonic organisms to shore, affecting the success of larval recruitment and the transition of organisms from larval to juvenile stages.

Other Anthropogenic Influences

Other human-induced environmental changes also affect marine populations, although they vary regionally and their extent is disputed. For example, McGowan (1990) reported no detectable change of pelagic species or of ecosystem structure in the California Current ecosystem despite extensive harvesting (fishing) of top predators and vastly increased inputs of pollutants. In contrast, the Baltic Sea ecosystem has changed significantly in the past 50 years in response to eutrophication (Kullenberg, 1986).

The incidence of unusual, and sometimes harmful, phytoplankton blooms is increasing in coastal waters around the world. The evidence is particularly compelling in European and Japanese waters, where long-term water quality monitoring programs exist. The precise causes of any bloom event are difficult to ascertain, but there is increasing evidence that unusual phytoplankton blooms are related to changes in nitrogen-silicon ratios caused by eutrophication. The food-web consequences of the global epidemic of noxious phytoplankton blooms could be severe in some areas.

Fishing activity also changes the structure of marine ecosystems, although the effects of overfishing are often difficult to resolve from long-period cycles in organism abundance. Overfishing of the Georges Bank off the northeastern United States has changed the composition of fish species. From the mid-1960s until the early 1970s, herring and haddock declined by about a factor of 10 due to severe fishing pressure. At the same time, squid, dogfish, and sand lance increased, probably because they filled the ecological niches of depleted haddock and herring stocks (Sissenwine, 1986).

Long-term studies of some coastal benthic communities suggest that they have changed significantly owing to eutrophication. A 20-year time series of benthic species abundance data at a station in Puget Sound suggests that eutrophication may be causing shifts in the dominant species as well as increasing the magnitude of population fluctuations (Nichols, 1985). Yet, even with decadal time series, cause and effect are difficult to ascribe unambiguously, in part because anthropogenic effects are difficult to distinguish from natural changes.

Research Strategies

The complexity of biological systems and their variability in time and space pose practical problems for designing programs and setting research priorities. Research based on the theme that food-web variability controls variability in fluxes of biologically important elements in the global ocean could take many forms; efforts must then focus on a subset of key questions and approaches.

One possibility is to take a comparative approach and focus studies on regions or times of the year with clearly distinguishable food-web structures, and to examine processes in the euphotic zone and in deeper waters. A second possible strategy is to plan biological studies to resolve seeming inconsistencies or contradictions obtained from geochemical measurements and models. For example, recent interest in vertical fluxes in the North Atlantic (Altabet, 1989) were inspired in part by geochemical studies indicating that conventional views of productivity and particle flux in nutrient-poor waters were inconsistent with geochemical data.

A third possible strategy is to study regions of the ocean that are anomalous vis-à-vis standard paradigms. What controls productivity in nutrient-rich areas of the sea, such as the subarctic Pacific and the equatorial Pacific? If this question could be answered unequivocally, it would indicate significant progress toward a general understanding of oceanic productivity.

In support of all three strategies is continued research on the ecology, physiology, and molecular biology of representative species from specific oceanographic regimes. Without an understanding of the basic biology of individual organisms, one cannot hope to understand how the marine food web works or to predict how the ecosystem will respond to change.

Technologies and Approaches for the 1990s

The pace of scientific progress is often closely coupled with the development and application of new technologies. Several technologies and approaches will aid the study of marine ecosystems in the 1990s and could lead to important breakthroughs.

Satellite Remote Sensing

By the mid-1990s, three variables will be measured simultaneously by satellite for routinely characterizing ecosystems and related environmental factors. The three variables are sea surface temperature; sea surface and near-surface ocean color to determine chlorophyll and water clarity; and sea surface wind fields for estimating rates of vertical mixing, air-sea gas exchange rates, and other wind-related processes, such as the seasonal changes in the depth of the surface ocean mixed layer.

Numerical Modeling

Two developments in modeling should make significant contributions to ecosystem studies in the 1990s. First, models are being developed that can be used to help form hypotheses regarding the role of oceanic biota in global nutrient budgets. These models ultimately will merge basic mathematical descriptions of biogeochemical cycles with general circulation models and, from given starting conditions, will attempt to predict the evolution of fluxes over time. Global models will be particularly useful conceptual tools as techniques are developed to incorporate tracer distributions and satellite data into modeling procedures. For studies of marine populations, models based on individual organisms show promise because they allow treatment of biological variability at the species level.

Molecular Biology

Marine organisms in general have not been studied as extensively as their terrestrial counterparts; relatively little is known about the biota of the world ocean. Barriers to rapid advancements in biological oceanography include the inability of conventional technology to distinguish rapidly among marine taxa and to resolve important questions related to marine community structure, flow dynamics, and their interrelationships. Similarly, advances in marine biology and biological oceanography are limited by the paucity of fundamental knowledge of the genetics, molecular biology, biochemistry, and physiology of marine organisms.

A new suite of elegant and sophisticated technologies and instruments for molecular biology has been developed in the past two decades that could greatly facilitate studies of marine organisms. The technologies of molecular genetics are now applicable to ocean science. These technologies, which allow one to manipulate and probe the most fundamental life processes in ways that were not previously imagined, will revolutionize knowledge of the processes and mechanisms that regulate population, species, and community structures in ocean ecosystems.

In general, molecular biology will aid the study of marine ecosystems in two ways: it will help to determine the physiological state of organisms, and it will help to identify and characterize the genetic structure of marine populations. Work in these areas will help both to identify the causes of biological variability in the ocean and to understand the implications of this variability for the stability and ecological balance of human-impacted ecosystems. For example, these techniques were used to discover archaebacteria and prochlorophyte phytoplankton, to study the role of marine viruses, to determine the diversity of marine bacteria, and to study the enzyme activity of marine organisms. Research in these areas is in its infancy, and new techniques of molecular biology will undoubtedly continue to play an important role in future research.

Acoustics

Sound is an extremely useful tool in biological and fisheries oceanography. The scattering of sound by organisms at many different trophic levels can be used for a variety of purposes. Schools of fish and patches of plankton can be located and tracked acoustically. It may eventually be possible to distinguish living from nonliving scatterers and to identify the biological scatterers by species. It may soon be possible to estimate biomass acoustically as a function of trophic level in the ocean. Sound scattering has been used commercially since the 1930s to locate fish schools, but only recently have multifrequency systems been available for quantitative study of animal plankton. The Multi-Frequency Acoustic Profiling System is capable of profiling zooplankton in the size range of 0.2 to 10 millimeters. General application of acoustical technology will require the development of inexpensive equipment and techniques to analyze and use the large volumes of data generated.

Bio-optics

Fluorometers, transmissometers, and spectroradiometers are used to measure phytoplankton populations, the turbidity of the water column, and the amount and wavelength of light that penetrate beneath the ocean surface at a given site. Correlating site measurements with measurements from satellite ocean color sensors provides the means to extrapolate phytoplankton measurements to a global scale. Mooring optical instruments together with current meters and temperature and salinity sensors provides a technique for collecting long (months) and highly resolved (minutes to hours) time-series measurements, permitting biological oceanographers to study what physical factors control phytoplankton populations. Moorings contribute data on variation over time and depth, whereas satellite sensors provide information on variation over the global ocean surface. Flow cytometry is another optically based technology that is extremely useful for characterizing the size and pigment composition of phytoplankton and bacteria and for sorting populations based on these and other criteria.

Imaging for Organism Enumeration

New techniques for imaging organisms in situ, now available, show promise for widespread application in the 1990s. These technologies include schlieren video systems and holography, which have been used in the laboratory to study zooplankton feeding behavior. When successfully applied in situ, three-dimensional analyses of individual organisms and their spatial relations will be possible on scales sufficient to resolve the behavior of individual organisms.

Time Series

The concept of acquiring long time series of key ecosystem variables at important locations in the global ocean is certainly not new. Yet, with the possible exception of tide-gauge stations, the routine collection of temperature data by commercial ships, and a few simple physical measurements, time-series measurement programs are rare. A notable example of long time-series biological measurements is the Continuous Plankton Recorder Surveys of marine plankton in the North Atlantic Ocean. Ongoing programs measuring biological variables (e.g., the California Cooperative Oceanic Fisheries Investigation) are generally poorly funded. Virtually all recent planning reports stress the importance of long time series to resolve key global change issues and to describe the fundamental attributes of marine ecosystem dynamics. Satellite sensors and bio-optical moorings provide one level of information, but many more in situ observations are needed. Federal agencies recently have recognized the importance of financially supporting long-term measurement programs. For example, NSF supports time series stations at Bermuda and Hawaii, and the National Oceanic and Atmospheric Administration and the Office of the Oceanographer of the Navy are planning the U.S. contribution to a global ocean monitoring system. These time-series stations could be considered the beginning of the biological portion of a global ocean observing system.

Ideas and technologies are in place to make significant progress during the next 10 years in determining the role of marine ecosystems in global ocean biogeochemical cycles and the effects of global change on marine ecosystems. Available technologies range from molecular probes to satellite sensors. The ideas cover a comparable range of scales, from hypotheses about predator-prey encounters at centimeter-length scales to those about interannual variability in global ocean primary production. During the past five years, biological oceanographers have conducted a number of workshops and issued a large number of planning documents and reports (Appendix III). The field is obviously not idea limited.

DIRECTIONS FOR COASTAL OCEAN PROCESSES

Summary

In the coming decade, coastal research will be more interdisciplinary than it is now. Understanding coastal processes will require interdisciplinary studies of biological, chemical, physical, and geological processes. There will probably be considerable progress on the exchange of materials across continental shelves and between the ocean and the atmosphere. For example, physical mechanisms for cross-shelf exchange and their interactions with nonphysical mechanisms should be thoroughly studied. By the end of the decade, estimations of air-sea fluxes of momentum, heat, and gases in a nonequilibrium sea state (typical for the coastal ocean) should be possible. Further, the understanding of biological, chemical, and geological processes that affect these fluxes should have advanced substantially. Considerable progress should have been achieved in understanding the complex inner shelf (water depths of 3 to 30 meters), where measurements are difficult to make and processes difficult to model because of the many more factors that influence the system, compared to the open ocean. In the same vein, a more predictive understanding of the flux of materials through estuaries will emerge as our knowledge of the interactions of biological, geochemical, and physical processes improves.

Cross-shelf exchange and its related biological, chemical, geological, and meteorological components will be an active research area. So too will ocean fronts and their implications for biology, chemistry, and meteorology. Fronts are distinct boundaries between water masses and are nearly ubiquitous in the coastal ocean. The mechanisms that create them offer their own sampling and modeling difficulties.

Other areas of research are the global implications of coastal nutrient, carbon, and trace metal cycles and the study of ecosystem structures, which affect chemical cycles. Because of the diversity of coastal ocean regions, significant progress in understanding coastal processes may be achieved in some areas, but it is unlikely that results from all coastal regions can be integrated within the decade. Emphasis on toxic algal blooms, ecosystem structure changes, the invasion or dominance of nuisance species, and other human-induced biological effects may well increase.

In terms of facilities, it is likely that the demand for research aircraft will increase over the decade. The deployment of moored instrument systems will probably increase, especially with newly developed sensors, such as complete meteorological and wave measurements and underwater sensors capable of measuring biologically, chemically, and geologically relevant variables. Such comprehensive packages already exist or are under development, but their use will become more routine as the decade progresses. The need to study small-scale dynamic features, such as fronts on the continental shelf and wind-forced mixing in estuaries, will create a greater demand for towed devices that can sample rapidly and repeatedly in three dimensions. These too are becoming available but will be used more frequently in the future. Similarly, there will probably be a need for new sediment samplers that can also measure near-bottom currents and sedimentary conditions. Advances in remote sensing of coastal areas will benefit the field.

Introduction

The coastal ocean lies at the junction between land and the open ocean and includes estuaries and embayments. By virtue of its location, it is a setting of unusual societal importance. Most of the world's population centers are located near the ocean, so that pollution, recreation, and shipping impact the coastal environment and are likewise affected by coastal processes. As the U.S. population continues to shift toward the ocean, these considerations will become increasingly important. Economically, the coastal ocean is also of great importance, for example, in terms of mineral (especially petroleum) exploitation, recreation, and fisheries. The conflicts among uses of the coastal region have heightened the public's awareness of the region—and of the need to study it in detail.

The coastal region is defined here as the portions of ocean and atmosphere extending seaward from the surf zone and the heads of tidal estuaries and overlaying the continental shelf, slope, and rise. Geologically, this region of the continental margin forms the transition between the thick continental crust and the thinner oceanic crust, both of which float on the underlying mantle. The continental shelf is essentially the submerged edge of the continental crust. Broadly speaking, continental margins are of two types (Figure 3-3). Those on the leading edges of crustal plate motions (often near trenches) tend to be characterized by narrow shelves, (e.g., the West Coast of the United States). Margins on the trailing, relatively inactive edges of continents tend to be characterized by broad, relatively flat shelves (e.g., the U.S. East

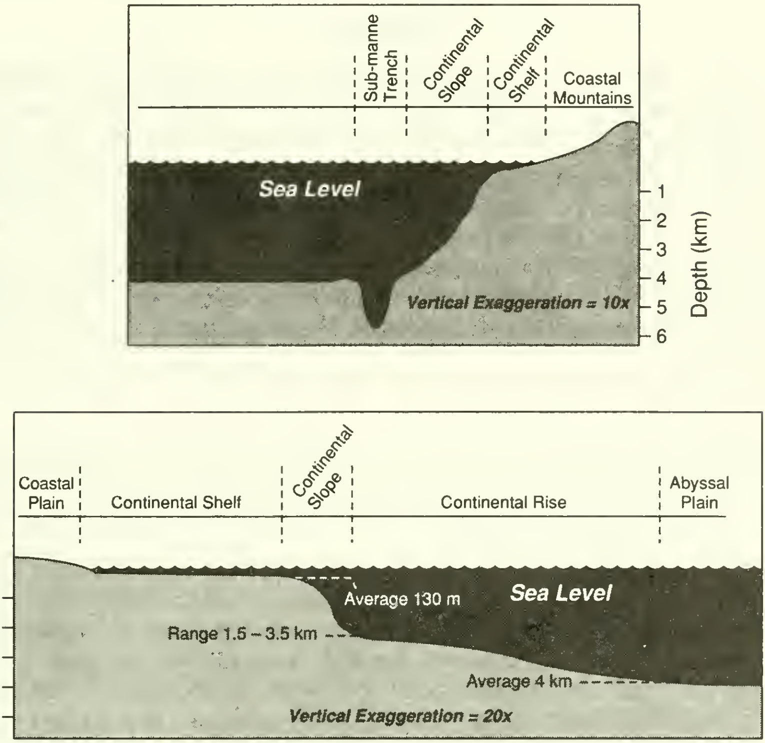


FIGURE 3-3 Typical profiles of two common types of continental margins. *Upper panel*: A collision margin typical of the Pacific coast of South America. The presence of a submarine trench, a narrow continental shelf, and a landward mountain range characterize this type of margin. *Lower panel*: A trailing-edge margin typical of much of the Atlantic Ocean. The presence of a continental rise, a broad continental shelf, and a coastal plain are characteristic of this type of margin.

Coast). The margins are often greatly modified by erosion and sediment deposition, processes that tend to carve out submarine canyons and fill in basins, respectively.

The following sections describe processes that make the coastal ocean unique and discuss some scientific issues that will be particularly important over the coming decade. Emphasis is on interdisciplinary aspects because it is likely that most important scientific and societal problems cannot be tackled successfully without a comprehensive approach.

Processes

The lateral boundaries and shelf-slope topography that characterize continental margins substantially determine the nature of coastal currents. For example, on a rotating planet, nearly steady currents are constrained from crossing isobaths (lines of constant depth). As a result, flow in the coastal ocean tends to parallel the coast, and exchange between waters over the continental shelf and the adjacent deep ocean is inhibited. Thus in many cases, distinct shelf water masses form, and the shelf represents a partially closed chemical and biological system. Fronts often mark the boundaries between these coastal and oceanic systems, and these fronts have their own important biological and atmospheric effects.

Wind-driven currents over continental shelves tend to be particularly energetic because the coastline interrupts water transport in the turbulent layer in the upper ocean. This interruption leads to a connection between surface winds and currents deeper in the water column. The resulting currents flowing alongshore below the turbulent surface layer dominate variability in most places over the continental shelves. Wind-driven currents are understood well enough that models are able to predict the speed and direction of coastal currents, as shown by the close agreement between observed and predicted currents shown in Figure 3-4.

Of broader importance to coastal ecosystems is the related onshore-offshore circulation, including the coastal upwelling of cold, nutrient-rich subsurface waters. Their temperature leads to the unusually cool, stable atmospheric conditions that characterize the U.S. West Coast during spring and summer. The upwelled nutrients fuel marine plant growth, leading to high biomass throughout the food web and some of the world's greatest fisheries, including those off the West Coast and off the coast of Peru. Upwelling can also intensify the transfer of organic materials from the surface to the seafloor in such areas. For example, off Peru, as much as one-half of the carbon fixed by phytoplankton production induced by upwelling may be deposited on the bottom. Upwelling in the coastal ocean can also be caused by factors other than wind. For example, upwelling of nutrient-rich water along the inshore edge of the Gulf Stream does much to stimulate productivity off the southeastern coast of the United States, as determined by chlorophyll measurements (Figure 3-5). Whatever its cause, upwelling contributes to the well-known high biological productivity of the coastal ocean (Figure 3-6). Estuaries and coastal embayments, on

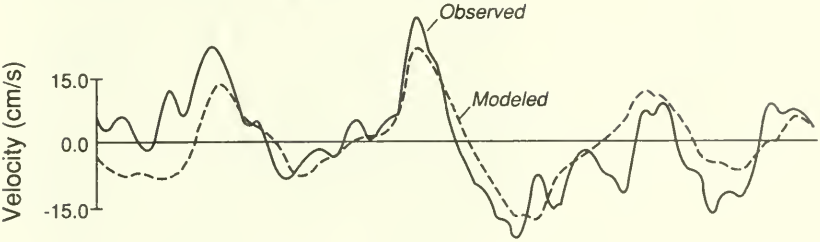


FIGURE 3-4 Observed (*solid line*) and modeled (*dashed line*) alongshore currents from over the continental shelf off Oregon, summer 1978. Positive velocity denotes northward flow. After Battisti and Hickey (1984).

the other hand, owe their high biological productivity to nutrient inputs from the land and density-driven internal circulation that serves to retain and enhance the recycling of these nutrients.

Sea ice is important in controlling air-sea fluxes in coastal regions when it forms there. Ice cover decreases heat, moisture, and gas fluxes and modifies momentum fluxes. During the formation of ice, salt is excluded, creating saltier adjacent water. These dense water masses can sink, impacting an entire basin through thermohaline circulation (see "Directions for Physical Oceanography"). Freshwater generated by ice melting stabilizes the water column, thus helping to prompt the spring phytoplankton bloom.

Tidal currents are sometimes enhanced over the continental shelves by physical resonances taking place in bays, such as in the well-known Gulf of Maine-Bay of Fundy example. Strong tidal currents intensify near-bottom mixing that can extend to the sea surface in shallow regions such as Georges Bank. This mixing and the resulting circulation enhance nutrient availability in the upper ocean, cause high primary productivity, enrich fisheries, and increase the transfer of organic material to underlying sediments. Energetic tidal currents can reinforce the many physical processes (including waves and wind-driven currents) that increase sediment resuspension and transport as well as the transport of chemicals that adhere to the particles.

Continental shelves are the transition zone between the land and the ocean and are thus particularly important in processes involving sediment and chemical fluxes. Freshwater outflows propel currents with distinct properties. Sediments from the land are

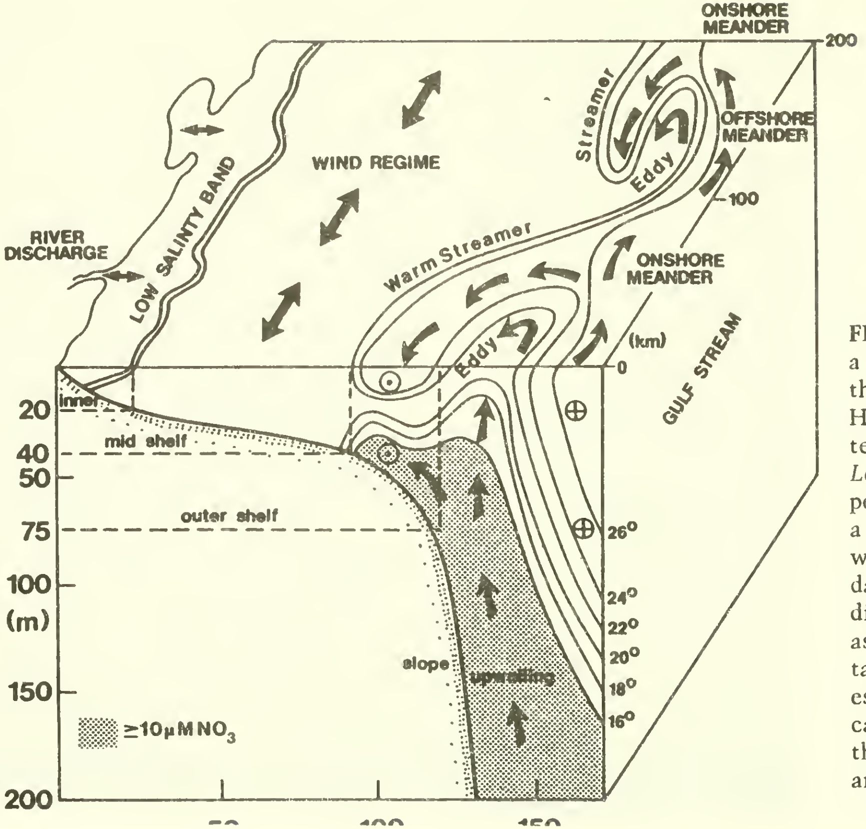
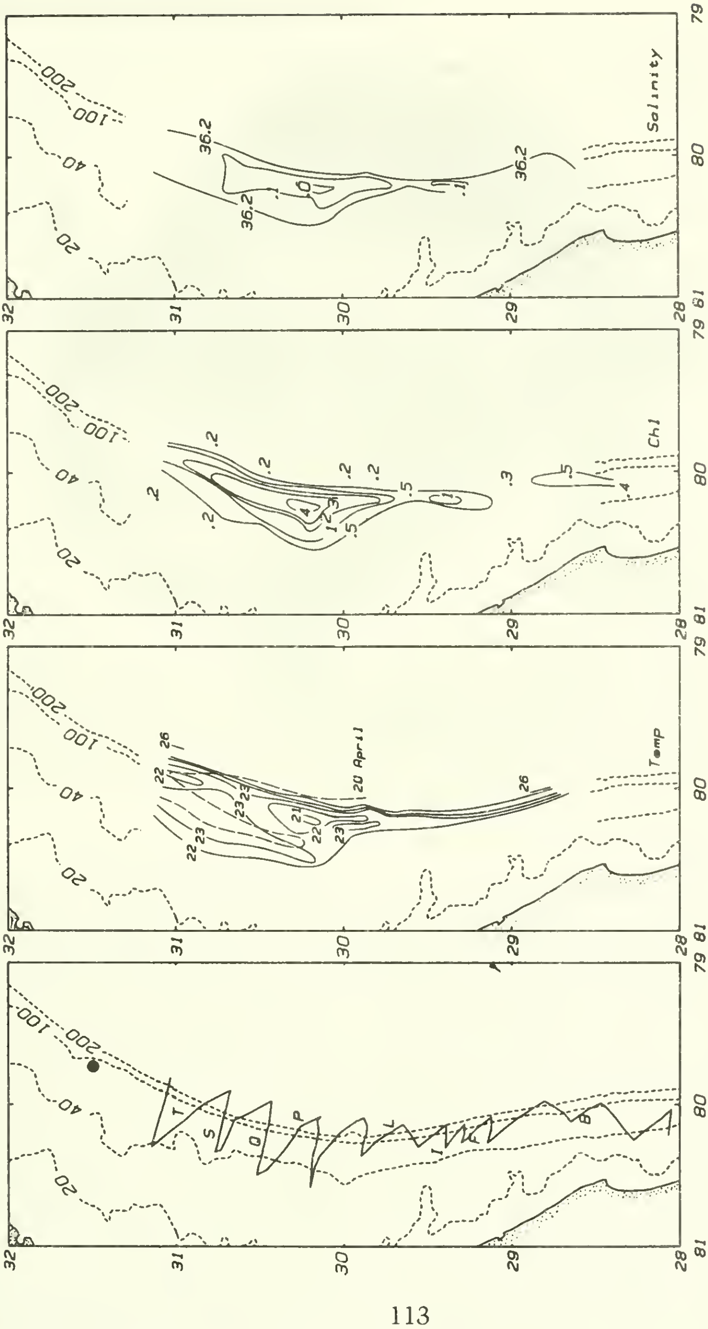


FIGURE 3-5 *Upper plate*: Schematic of a Gulf Stream frontal eddy (shingle) off the U.S. southeast coast south of Cape Hatteras. Upwelling of nutrient-rich waters occurs in the cold core of the eddy. *Lower plate*: Cruise track, surface temperature, chlorophyll a, and salinity across a Gulf Stream frontal eddy off the southwest U.S. coast on April 20–22, 1979. The dashed line in the temperature frame indicates Gulf Stream surface thermal front as determined by satellite-derived frontal analysis on April 20. Note that highest chlorophyll values (>4 mg/m^3) are located within the upwelled cold core of the eddy. Figures from Lee et al. (1991) and Yoder et al. (1981).


Salinity
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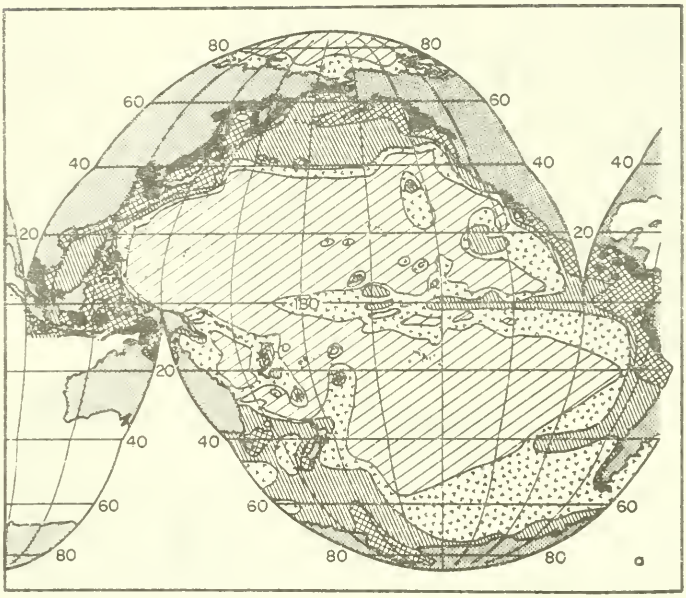


FIGURE 3-6 World ocean primary production according to Koblents-Mishke and coworkers on an equal area projection. Productivity categories are, from low to high, <36, 36-54, 54-90, 90-180, >180 gC/m^2/yr. Note that most of the areas of high productivity are located on the ocean margins. From Berger (1988).

often deposited on the continental shelves, although they are sometimes transported to the slopes and deep ocean later. Sedimentary conditions on the shelf are far from static: numerous physical and biological processes can lead to reworking of the sediments and to their eventual transport to other locations. New evidence suggests that the shelf can be a source of particulates that accumulate within estuaries together with sediments delivered to the estuaries by rivers and shoreline erosion. Over geological time scales, the fates of sediments can vary widely with sea level; shelf processes can differ markedly, depending on how much of the shelf (or slope) is exposed above the sea surface. Coastal waters also receive chemicals and particulates weathered from continental rocks and transported to the ocean by rivers, groundwater, and winds. When these chemicals reach the coastal ocean, they are transformed or removed, so that although the properties of the estuarine waters may differ from those of the open ocean, shelf waters closely resemble open ocean water.

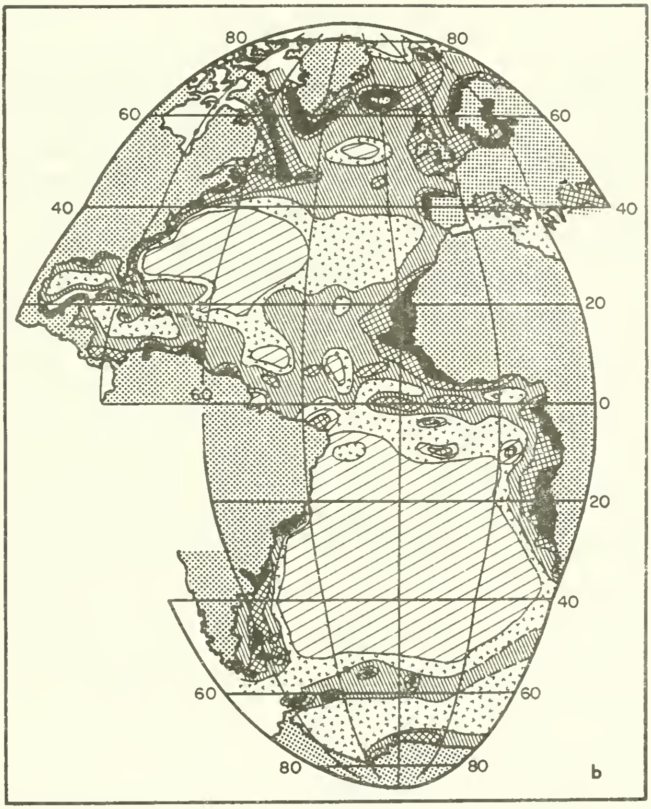


FIGURE 3-6 *Continued*

Physical processes on the scale of millimeters to kilometers have a major impact on the behavioral responses, feeding rates, interactions, and distributions of plankton, fish, and benthic invertebrates in the coastal ocean. For example, coastal fronts, island wakes, tidal flows, and vertical circulation cells are only a few of the many types of physical phenomena that can aggregate organisms or alter their behavior. Moreover, turbulence and small eddies on the scale of millimeters to meters partially determine the encounter rates of herbivores feeding on passive phytoplankton and bacteria and of predatory interactions among smaller pelagic organisms. An understanding of the effects of water movements on the behavior and distribution of organisms in the ocean will be one of the most challenging aspects of future research, particularly in coastal areas, where both physical processes and organisms are especially diverse and numerous.

Future Directions

The worldwide coastal ocean exhibits vast geographical diversity, depending on the size and openness of bays and estuaries; the width of the continental shelf; the proximity of strong oceanic currents; the strength of tides, winds, river runoff, and surface heat fluxes; and other characteristics. It is clearly impractical to explore fully the biological, chemical, geological, meteorological, and physical structure and variability of every estuary or shelf region of the United States, let alone of the world. One way to proceed is to identify the most significant physical-meteorological processes that to some extent act on all the world shelves and coastal waters. Each physical process and its effects on the biology, chemistry, and geology of the local area could then be studied in a prototypical environment (not limited to U.S. waters) where the process tends to predominate. The results of such interdisciplinary studies could be used to improve our modeling capabilities, enhancing our ability to model more typical shelves or estuaries where a combination of processes interacts. Although this approach is not a panacea, it can at least define the information needed to gain a desired level of understanding of a given coastal region. Within this broad approach to the coastal ocean, a number of important themes will be common to any detailed study of processes.

Air-Sea Interactions

The atmosphere is a major driving force of coastal ocean processes, through both its role in driving currents and its direct and indirect controls on biological and chemical processes. For example, wind-driven coastal upwelling can provide nutrients to the euphotic zone, leading to enhanced primary productivity, and atmospherically generated turbulence can increase predator-prey encounters among plankton (Rothschild and Osborn, 1988). Each of these biological processes results in distinct chemical transformations as well.

Present knowledge of atmospheric effects on the coastal ocean is limited to the effects of large-scale (500-kilometer) atmospheric features. This knowledge is useful for predicting alongshore currents or estimating the transport of dust particles from land to ocean (eolian deposition). Smaller scales in the wind field seem to be more important in determining cross-shelf currents; yet small-scale coastal winds are poorly observed and understood. Interaction of the atmosphere with the coastal ocean on these important scales of tens to hundreds of kilometers is not well-understood.

Air-sea fluxes of momentum and heat, for example, are not adequately characterized in present models, which do not take into account small-scale variability, directional offsets between the wind and waves, limited fetch, and limited water depth (which characterize the coastal environment; Geernaert, 1990). In addition, thermal fronts, which occur throughout the coastal ocean, greatly perturb the atmospheric layer directly above the sea surface and sometimes perturb weather systems. Further, the coastal topography helps to generate small-scale disturbances in the surface winds that can affect currents over the shelf. Air-sea fluxes of particles and chemicals, known to be important, must be a significant part of any study. Until we can quantify the air-sea momentum, heat, and chemical fluxes in this complex environment, we cannot understand the coastal ocean system as a whole.

Air-sea exchange is complex, but answers to the questions must be found. The atmosphere is the basic driving force of many coastal ocean processes. Ocean fluxes, especially heat fluxes, are critical to properties of the atmosphere. Air-sea exchanges that govern the effects of ocean and atmosphere on each other need to be quantified.

Cross-Margin Transport

The interaction of currents with bottom topography tends to isolate continental shelves from the rest of the ocean, although the strength of this isolation is significantly modulated by other processes. Even when the isolation is especially strong, shelf waters resemble the open ocean more than they resemble estuaries. It is difficult to identify which processes determine the cross-margin fluxes of water, particulates, chemicals, and organisms within estuaries, between estuaries and the shelf, on the shelf, and at the shelf-ocean boundary. The relative importance of such factors as wind-driven motions, frontal instabilities, turbulent boundary-layer transports, exchanges through submarine canyons, and the sinking of dense waters has not been evaluated. The difficulty is ultimately their episodic nature in terms of both location and time. Each has distinct effects on biological, chemical, and geological processes, so that interest in them is not limited to physical oceanographers.

Information on cross-margin transport is critical to all subdisciplines of coastal ocean science. Alongshore gradients of most characteristics tend to be small relative to cross-shelf gradients, and alongshore currents are relatively well understood. It is cross-shelf transport, or its absence, that shapes many distributions, such as those of sediments, that are of scientific interest. Estuarine and cross-shelf exchange is also of interest from a societal standpoint, for example, in determining the fate of riverine inputs of excess nutrients or pollutants. Thus it seems likely that estuarine and cross-shelf exchanges will be a central focus of future efforts in coastal ocean science.

Carbon Cycles

An important and controversial question in oceanography is, What is the role of the coastal ocean in global cycles of carbon, oxygen, nitrogen, and other significant elements? The coastal ocean occupies approximately 20 percent of total ocean area, yet accounts for approximately 50 percent of ocean primary production and approximately 50 percent of global ocean nitrate assimilation by phytoplankton (Walsh, 1991). Describing the mechanisms controlling cycling rates of essential elements has taken on new urgency because of the recently recognized potential for human alteration of global chemical cycles. Biological processes mediate the cycling of many elements and control the fate of numerous materials that enter the ocean. Constructing accurate models of biological controls and predicting their effect on the fate and transformation of dissolved substances and particles in the ocean are severely limited by our lack of understanding of the structure and function of marine ecosystems and their responses to physical and chemical processes. Elucidating these mechanisms is critical to understanding the coastal ocean because of its generally high productivity (and thus its processing capability), its substantial biological variability in space and time, and its role as a conduit between the continents and the deep ocean basins.

A major uncertainty in models of global change, including climate change, is the role of biological processes in mediating and controlling geochemical cycling of important elements. Most scientists agree that biological processes play a key role in the ocean carbon cycle and the cycle of nitrogen, oxygen, and related elements. However, the possible role of marine plants as a sink for carbon dioxide from human activities is highly controversial, and no generally acceptable model has been proposed to explain how the transfer of carbon from the ocean surface to the seafloor (the biological pump) should be working significantly faster now than before the Industrial Revolution. This is an important issue to be considered during the next decade. Understanding ocean margin food webs is of particular interest because they can be altered by eutrophication and other human activities.

In the ocean, the amount of organic material transferred vertically from the surface to the bottom and horizontally from estuaries to shelf waters to the deep ocean is not a simple linear function of primary production; nor are burial rates of organic matter in ocean sediments. The amount of material transported depends on the physical and chemical characteristics of the environment (e.g., rates and mechanisms of nutrient delivery) and on various largely unappreciated characteristics of the species composition and structure of marine food webs in the euphotic zone, deeper in the water column, and in and around the seafloor. Some biogeochemical cycling processes are summarized in Figure 3-7.

Particle Dynamics

Research in several areas needs to be initiated to improve our basic understanding of particle dynamics. Some of these areas have been mentioned, for example, the cross-shelf transport mechanisms and the use of narrow coastal margins with significant sediment inputs to model transport conditions during past times of lower sea level.

Among other research possibilities is the need to test the wide range of theoretical models for sediment transport that evolved in the past two decades. For example, models have been developed to describe the coupling between slowly varying currents and surface gravity waves and to predict resulting sediment transport.

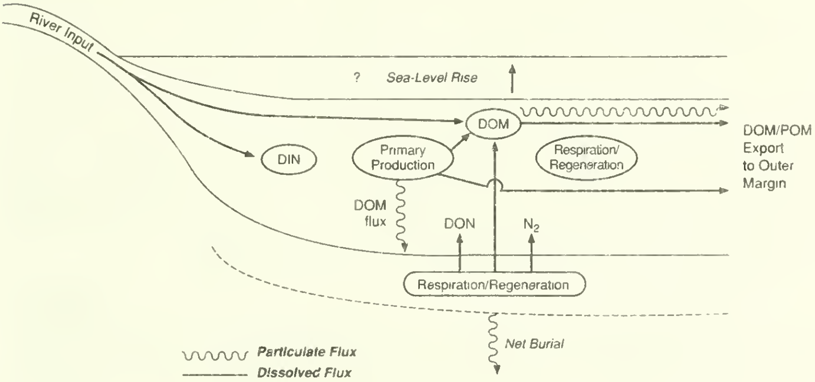


FIGURE 3-7 Schematic of some processes relevant to biogeochemical cycling on the inner continental margin; (DOM = dissolved organic material; DIN = dissolved inorganic nitrogen; DON = dissolved organic nitrogen; POM = particulate organic material). From Mantoura et al. (1991).

However, these models have received little or no testing in the laboratory or through field observations.

Muddy sediments are geologically relevant, and some research has been conducted on the transport of low concentrations of fine-grained sediments. Dense concentrations [>10 grams per liter (i.e., fluid muds)] are also observed in the marine environment, and their transport is poorly understood.

Carbonate sediments are widespread at low latitudes, but the effects of physical processes on their dispersal have not been thoroughly studied. Differences in the particle shapes and densities of carbonate sediments from more common sources make it difficult to extrapolate existing theory of sediment transport.

Theory regarding the formation of sediment layering within the seabed and its dependence on sediment transport and biological activity has evolved rapidly. Additional laboratory and field documentation is needed to link formative mechanisms and preserved strata.

The overall importance of the coastal ocean extends far beyond its relatively small areal extent. An environment of remarkably high biological productivity, this transition zone between land and open ocean is of considerable importance for recreation, waste disposal, and mineral exploitation. Such societal issues as pollution (in its many forms), bioremediation, waste disposal, and risk assessment cannot be addressed adequately until we make substantial advances in our basic understanding of the coastal ocean. A holistic approach to the coastal ocean system, blending marine meteorology with biological, chemical, geological, and physical oceanography, should enable us to progress sufficiently so that we will be better prepared to make the technical and policy decisions facing us over the next decades. Four issues of particular importance are air-sea interactions, cross-margin transport, carbon cycles, and particle dynamics. A balanced program would include studies focused on specific processes, long-term measurements, modeling, and instrumentation development. To take best advantage of the results of these studies, strong working relationships with the applied science communities need to be forged.

Coastal measurements will be an important part of a global ocean observing system because it is at the coasts that most countries, particularly developing nations, will make most of their measurements. Therefore, it is essential that the design of a GOOS include coastal measurements as a critical element of the system.

4

Human, Physical, and Fiscal Resources

HUMAN RESOURCES

Public and private institutions have developed an excellent graduate education system, yielding graduates employed in academia, government, and the private sector in the United States and abroad. The boundaries of oceanography are not well defined, and the field is characterized by many entry points from associated fields at various educational levels. Because of the diversity within the field and its relative youth as a separate science, a research oceanographer cannot simply be defined as one who holds a doctor's degree in ocean science. Many senior faculty in oceanography departments and institutions earned degrees in fields other than oceanography, and many scientists continue to enter ocean science from other fields. Nor can oceanographers be defined as those who perform basic research that is funded by the Division of Ocean Sciences of the National Science Foundation (NSF) or by the Office of Naval Research (ONR). Either definition misses many scientists whose primary activity is teaching, whose research is funded from other sources, or who are employed by federal agencies.

Ocean science will be characterized in the coming decade by a mixture of large multiple-investigator programs and individual investigations. The research will be only as good as the scientific talent that can be applied to the questions posed. Concern has developed regarding the potential shortage of Ph.D.s in science and engineering in the 1990s and beyond in terms of both number and quality. The oceanographic community has, however, questioned this assertion of a lack of qualified doctorates. This section discusses the demographics of oceanography and relates its characteristics to research needs.

In examining ocean science, the board asked eight specific questions:

- How many Ph.D.-level oceanographers are there, and at what rate has the number of Ph.D.-level ocean scientists changed over time?
- How many ocean science doctorates are produced annually?
- What is the present age profile of oceanographers in academia and the federal government, and has it changed over time?
- Has the field matured in terms of becoming a separate discipline?
- How has the percentage of women, minorities, and foreign nationals in the field changed over time?
- Has the field changed in terms of academic emphasis among the major subdisciplines [physical oceanography (P.O.), chemical oceanography (C.O) and marine chemistry (M.C.), marine geology and geophysics (MG and G), biological oceanography (B.O.) and marine biology (M.B.), and ocean engineering (O.E.)]?
- Has the balance of the field changed in terms of the relative size and importance of the major oceanographic institutions?
- How are research oceanographers supported? What is the ratio of institutional to federal salary support for the oceanography community as a whole?

Data Sources

Information was collected from a variety of sources. Data on the demographics of oceanography was obtained from biennial reports (1973 to 1989) issued by NSF, called *Characteristics of Doctoral Scientists and Engineers in the United States* (NSF, 1975; 1977; 1979; 1981; 1983; 1985; 1987; 1989; 1991). In addition, the Ocean Studies Board surveyed the major ocean science institutions and federal agencies (Appendixes IV and V). These two sources form the basis for much of the information presented. Additional information on faculty ages and number of Ph.D.s graduating was obtained from Joint Oceanographic Institutions, Inc.

(JOI). Data on ocean sciences grant recipient characteristics were obtained from NSF, and projected demands for Ph.D-level researchers were obtained from four major oceanographic research programs.

Results

National Science Foundation Surveys

Since 1973, NSF (through the NRC) has collected information on the employment and demographic characteristics of scientists and engineers with doctoral degrees in the United States. The NSF survey constituted a sample of the Ph.D. population, from which total population values were estimated. These estimates have substantial associated standard errors, so that statistical comparisons were not carried out. The number of oceanographers in all sectors of employment increased from 1,130 in 1973 to 2,460 in 1989 (Figure 4-1). From 1973 to 1981, the average annual rate of increase for academic oceanography was 4.7 percent; from 1981 to 1989, 4.0 percent. Oceanographers who consider teaching as

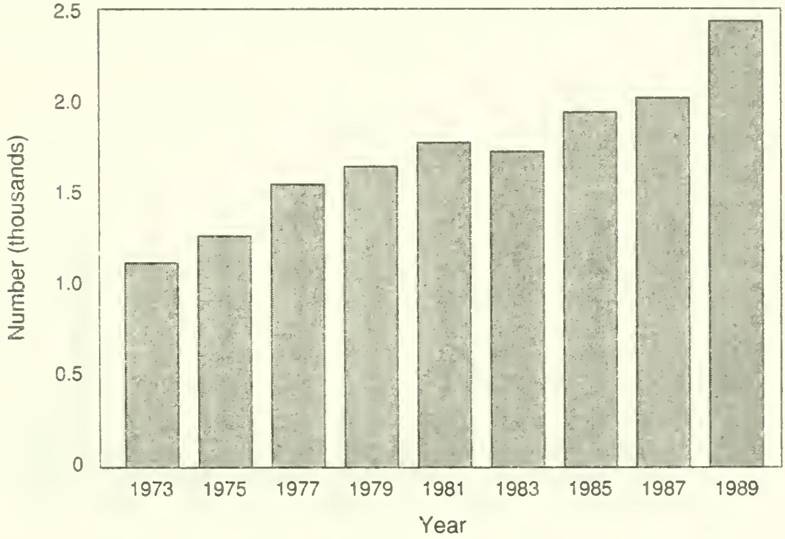


FIGURE 4-1 Change in number of Ph.D.s employed in oceanography over time (NSF data).

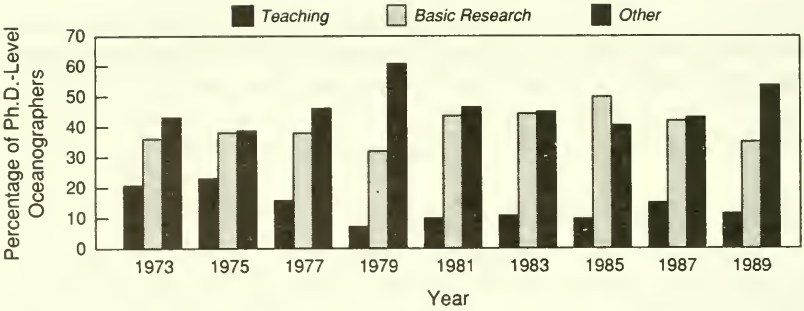


FIGURE 4-2 Primary work activity for Ph.D.s employed in oceanography (NSF data).

their primary work activity decreased from 21 percent in 1973 to 11 percent in 1989; the portion of oceanographers who consider basic research as their primary work activity fluctuated around 40 percent (Figure 4-2). Percentages in all employment sectors show no discernible trends over time (Figure 4-3). In 1989, most Ph.D.-level oceanographers—about 60 percent—were employed at educational institutions, including secondary schools, junior colleges, and four-year colleges. The federal government employed approxi-

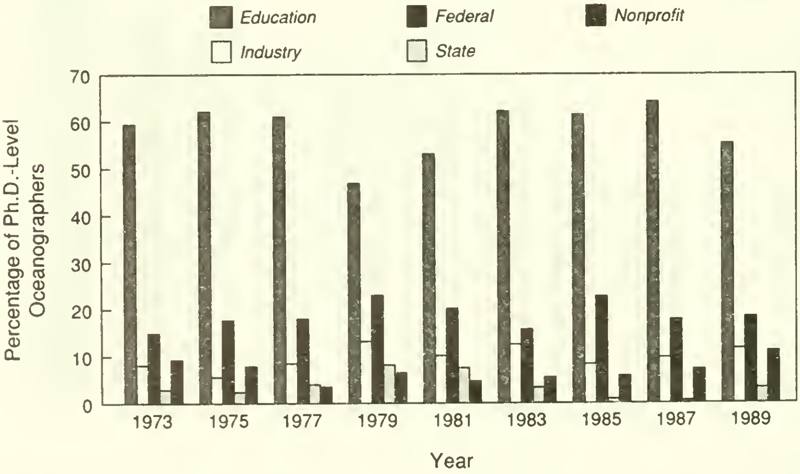


FIGURE 4-3 Employment sectors for Ph.D.s employed in oceanography (NSF data).

mately 20 percent of the nation's oceanographers; industry, about 10 percent; nonprofit organizations, 7 percent; and state governments, 4 percent. These percentages remained relatively stable over time.

The "maturity" of a discipline is the degree to which it is self-perpetuating and separate from other fields. Estimating the absolute maturity of a discipline is difficult, but examining changes in a number of indicators over time can show whether a field is advancing or declining. Two such indicators are the number of post-doctoral fellowships awarded and the ratio of faculty positions that are in the form of full professorships versus assistant professors. According to NSF data, the number of postdoctoral positions has increased, from an estimated 20 in 1973 to 84 in 1989 (Figure 4-4).

For new fields the ratio of full to assistant professors tends to increase over time because of the time required for faculty promotion and tenure, and the time universities need to establish tenured positions. For all science and engineering fields, the ratio has increased steadily over time, from 1.6 in 1973 to 2.4 in 1989 (Figure 4-5). The ratio for oceanography increased from 1.0 to 3.5 in the same period (Figure 4-5). The leap in the ratio in 1989 was due to a substantial increase in the number of full professors and a decrease in the number of assistant professors. The full to

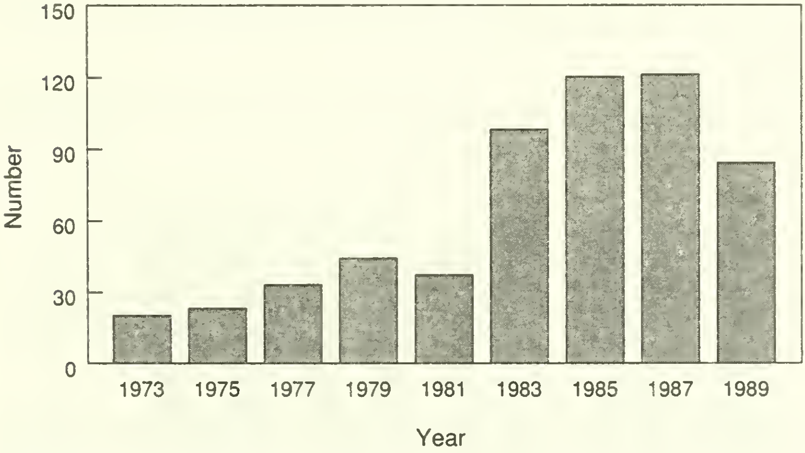


FIGURE 4-4 Postdoctoral fellows in oceanography (NSF data).

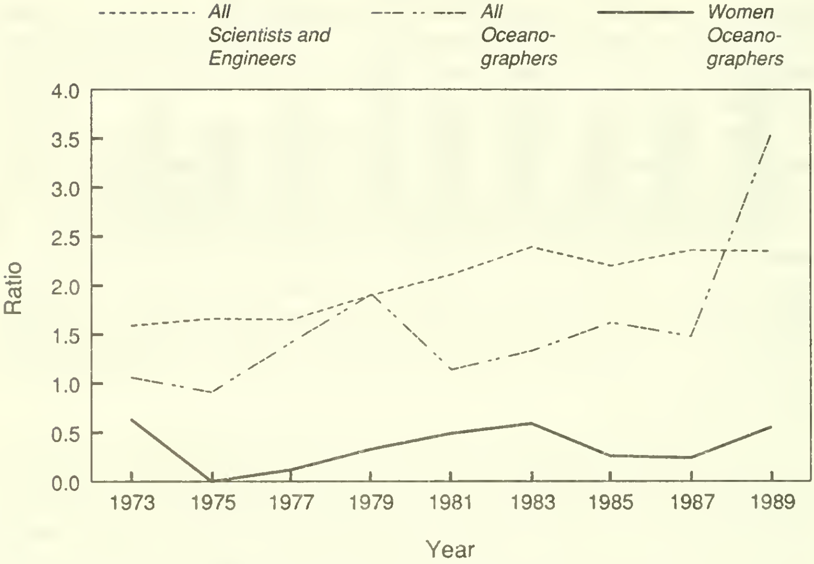


FIGURE 4-5 Ratio of full to assistant professors (NSF data).

assistant professor ratio is even lower for women, reflecting their relatively recent entrance into the field.

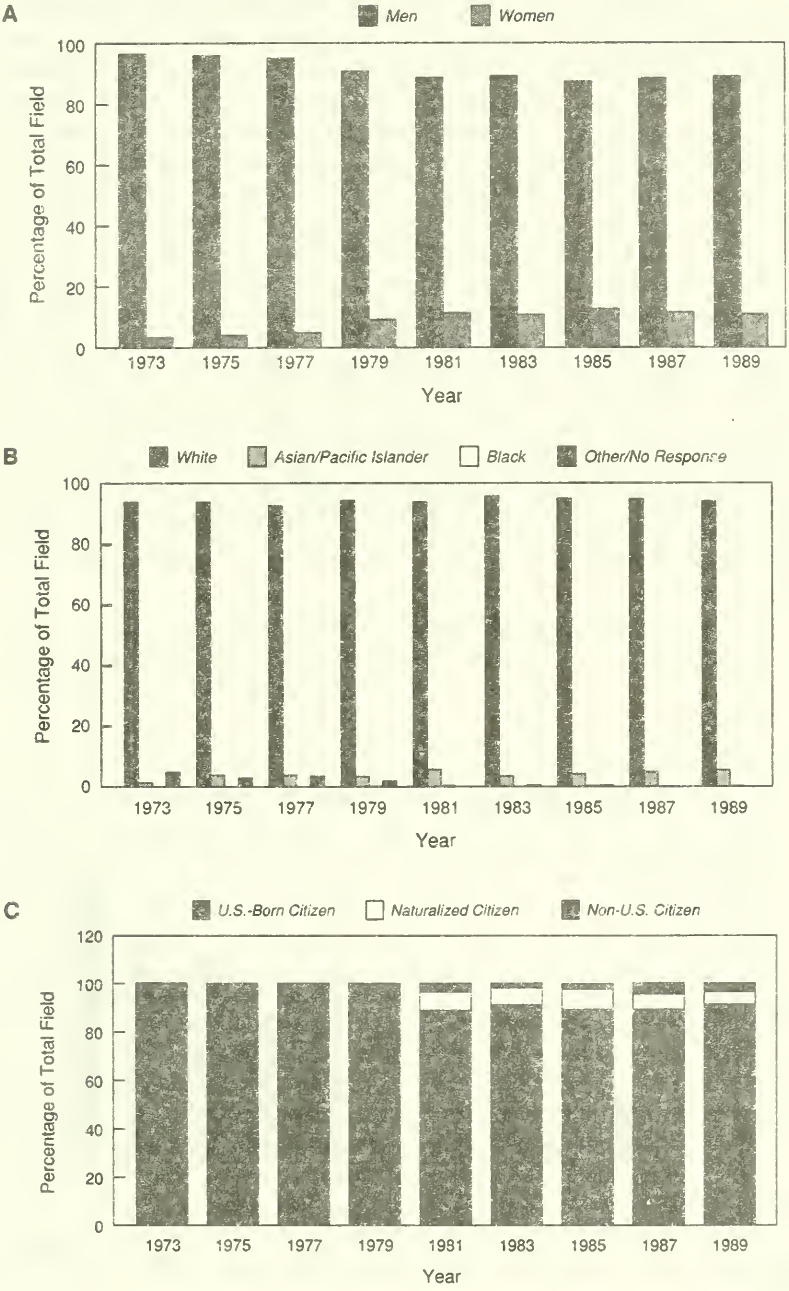
The proportion of the field made up of women increased from about 3 percent in 1973 to 11 percent in 1989 (Figure 4-6A). Minorities and foreign nationals practicing oceanography in the United States showed no significant trend from 1973 to 1989 (Figures 4-6B and C).

NSF data show that from 1973 to 1989, the median age of Ph.D. oceanographers shifted from the 35- to 39-year-old bracket to the 40- to 44-year-old bracket.

Ocean Studies Board Survey

Information on the potential supply of and demand for oceanographers is limited. Several attempts have been made to characterize the field over the past 20 years (NRC, 1970, 1972, 1981).

FIGURE 4-6 (See opposite page.) (A) Gender of employed oceanographers (NSF data). (B) Race of employed oceanographers (NSF data). (C) Nationality of employed oceanographers (NSF data).


A
Men
Women
Percentage of Total Field
100
80
60
40
20
0
1973
1975
1977
1979
1981
1983
1985
1987
1989
Year
B
White
Asian/Pacific Islander
Black
Other/No Response
Percentage of Total Field
100
80
60
40
20
0
1973
1975
1977
1979
1981
1983
1985
1987
1989
Year
C
U.S.-Born Citizen
Naturalized Citizen
Non-U.S. Citizen
Percentage of Total Field
120
100
80
60
40
20
0
1973
1975
1977
1979
1981
1983
1985
1987
1989
Year

For this study, the Ocean Studies Board (OSB) sent questionnaires to 52 oceanographic institutions, research laboratories, and academic members of the Council on Ocean Affairs, and to 8 federal agencies to assess the supply and demand within the academic and federal sectors. Responses were received from 40 academic institutions, including all the large academic programs and research institutions, and from 7 federal agencies (Appendixes VI and VII). Of the 40 institutions employing oceanographers in 1990, only 29 had employed oceanographers in 1970.

Replies to the OSB questionnaire indicated that the number of academic oceanographers increased from 540 in 1970 to 1,674 in 1990 (Figure 4-7). These include both teaching faculty and research faculty. It should be noted that some of the growth in the 1980–1990 period for academic oceanographers was due to the inclusion of 378 faculty members from two newly created units, at the University of Hawaii (UH) and the University of Washington (UW), that had not been included in the totals before 1990. At the same time, the number of Ph.D. oceanographers in federal agencies rose from 148 to 516. The annual rates of increase (percent) were

	1970–1980	1980–1990
Academic	6.4	2.6 (without UW and UH) 5.2 (with UW and UH)
Federal	9.9	3.1

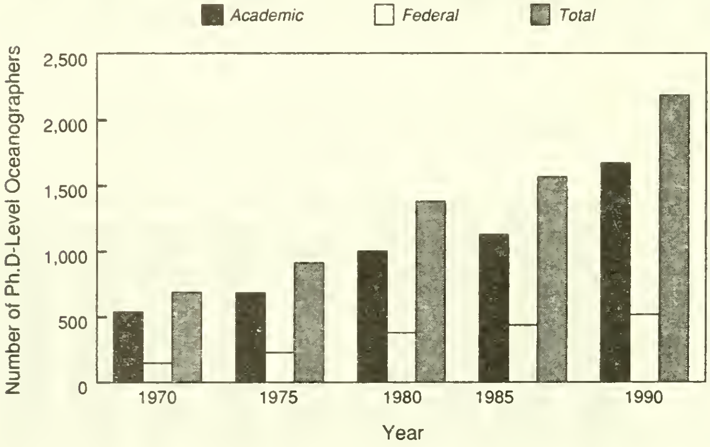


FIGURE 4-7 Ph.D.-level federal and academic oceanographers (OSB survey).

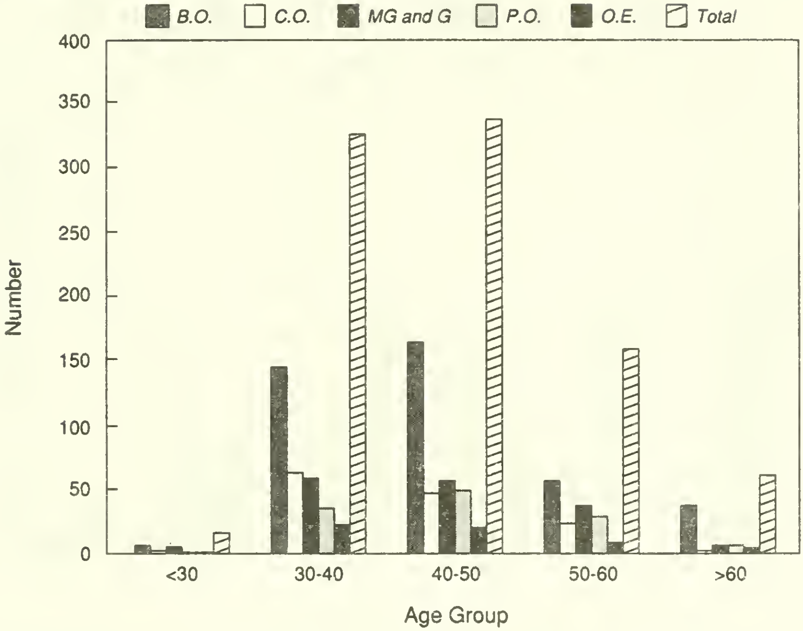


FIGURE 4-8 Age distribution of Ph.D.-level oceanographers in oceanographic institutions and universities (OSB survey).

Figures 4-8 and 4-9 show that for universities and government laboratories, respectively, the largest number of oceanographers in any age range falls in the 40- to 50-year-old category. The marked peak in the age distribution of federally employed oceanographers could reflect the establishment and expansion of federal oceanography programs in the 1970s.

The ratio of full to assistant professors in ocean sciences over the past 20 years has increased from 1.0 to 1.6 (Table 4-1). During roughly the same period, NSF data show an increase from 1.0 to 3.5. This reason for this discrepancy in unknown, although the large standard error in the NSF data makes comparisons difficult. Figure 4-10 shows the increase in Ph.D.-level staff by rank. The number of postdoctoral positions increased from 11 in 1970 to 111 in 1990, according to OSB data, compared with an increase from 20 in 1973 to 84 in 1989, according to NSF data.

Figure 4-11 shows changes in the number of Ph.D.-level oceanographers by discipline over time, as determined by the OSB sur-

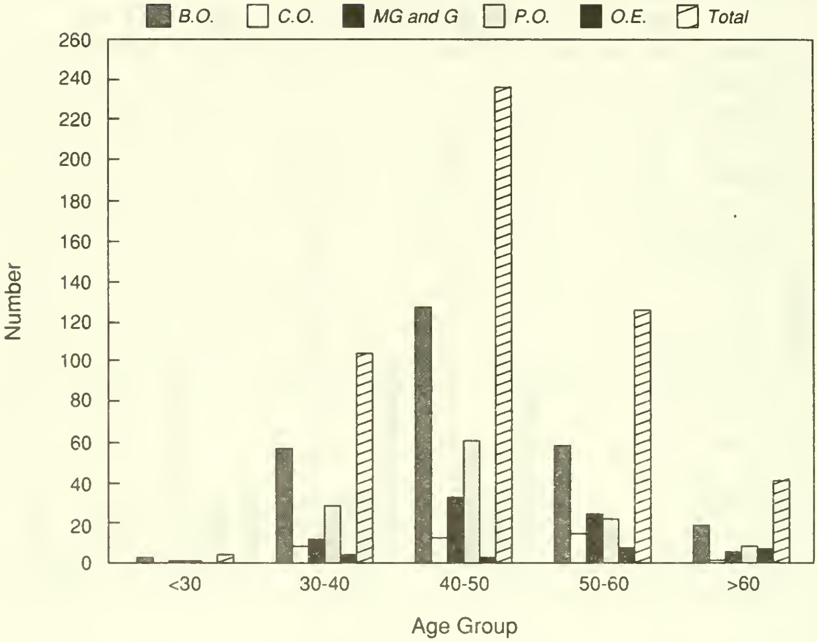


FIGURE 4-9 Age distribution of Ph.D.-level oceanographers employed by government agencies (OSB survey).

vey. The category that includes biological oceanography and marine biology continues to dominate numerically, reflecting the number of relatively small marine laboratories that focus on biological research. Except for a marked increase in ocean engineering, the relative ratios among the academic subdisciplines have not changed substantially over the past 20 years (Table 4-2). For

TABLE 4-1 Ratio of Full Professors to Assistant Professors in Oceanography, 1970–1990 (OSB survey)

Year	Ratio
1970	1.0
1975	1.2
1980	1.2
1985	1.6
1990	1.6

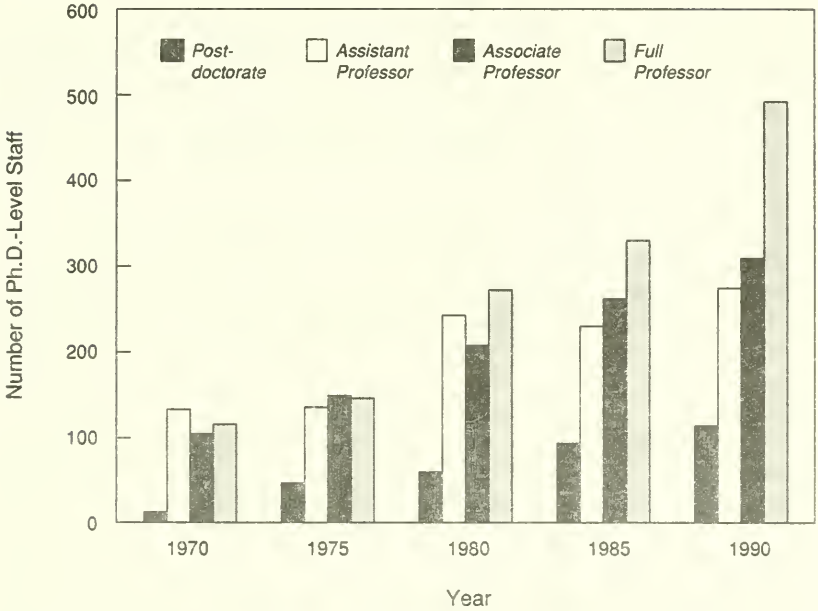


FIGURE 4-10 Rank of Ph.D.-level staff in academic institutions (OSB survey).

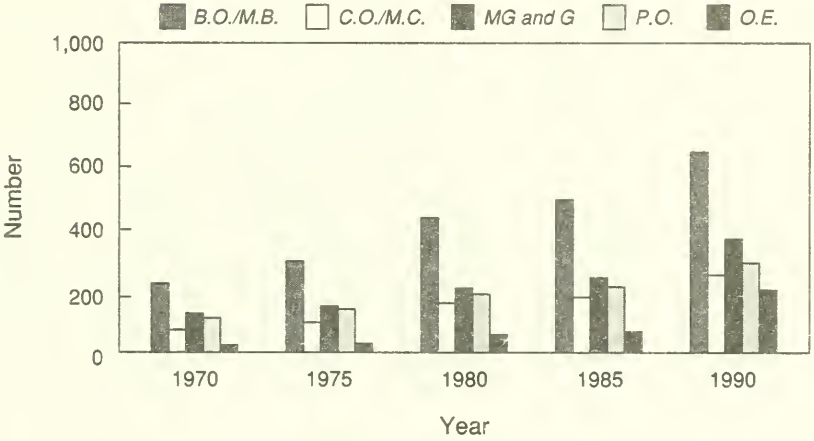


FIGURE 4-11 Change in number of Ph.D.-level oceanographers over time (OSB survey).

TABLE 4-2 Percentage of Ocean Scientists in Subdisciplines (OSB survey)

	Academic					Federal				
	1970	1975	1980	1985	1990	1970	1975	1980	1985	1990
Biological Oceanography/ Marine Biology	40.4	42.2	42.5	42.4	37.7	73.0	68.9	48.3	51.5	51.0
Chemical Oceanography/ Marine Chemistry	13.0	13.3	15.2	14.8	13.9	8.8	11.4	9.8	8.5	7.0
Marine Geology and Geophysics	22.6	21.3	19.7	20.2	20.8	3.4	2.6	13.5	14.0	13.4
Physical Oceanography	20.0	19.1	17.9	17.5	16.4	9.5	13.6	25.3	22.2	24.6
Ocean Engineering	4.1	4.1	4.7	5.0	11.2	4.7	3.1	4.2	6.9	5.8

federally employed oceanographers, the percentage of biologists has declined markedly, and the percentages of specialists in physical oceanography and marine geology and geophysics have increased (Table 4-2). The percentage of biologists in the federal government is considerably higher than in academia.

NSF, ONR, and JOI Institutional Data

The JOI members are 10 of the country's largest oceanographic institutions. In the most recent year for which data are available (fiscal year 1991), the JOI schools received 45 percent of the NSF Ocean Science Research Section funding and 42 percent of ONR funding (SE31 and SE32).

Figure 4-12 shows the percentage of faculty at JOI member institutions related to the total number of oceanography faculty, excluding data for the University of Washington and the University of Hawaii. In general, the percentage of the total oceanography faculty located in JOI institutions has not changed over time, although the percentage of marine engineers at JOI institutions may have increased, and biologists and chemists may have decreased (Figure 4-12). The JOI institutions, where the large ships are concentrated, still tend to dominate the field in the disciplines that require large ships, such as marine geology and geo-

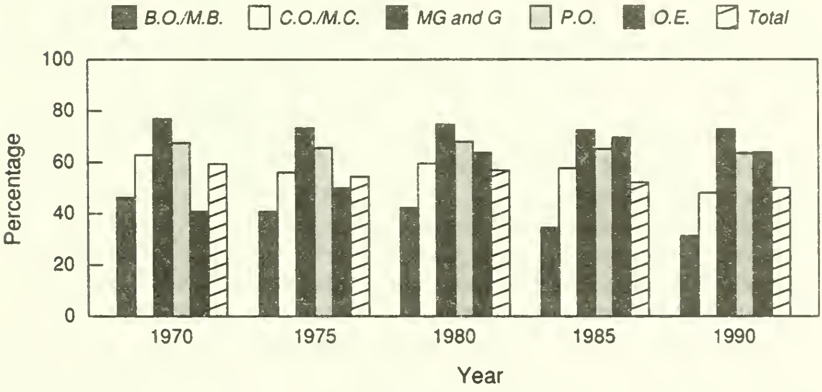


FIGURE 4-12 Percentage of oceanography staff at JOI institutions (OSB survey).

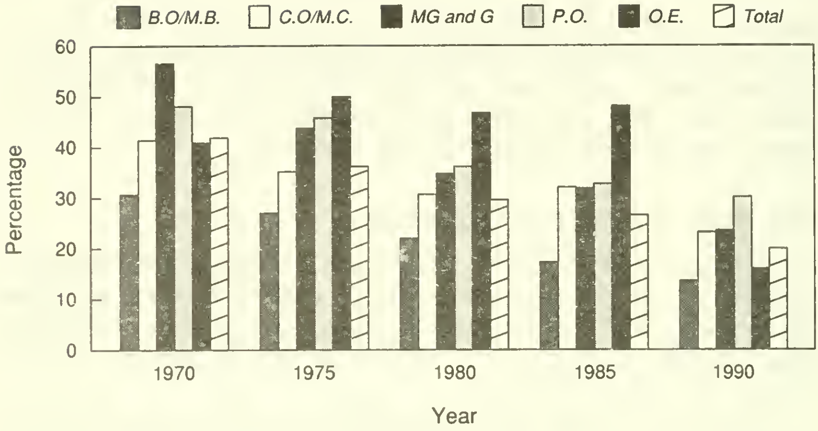


FIGURE 4-13 Percentage of oceanography staff at Scripps Institution of Oceanography and Woods Hole Oceanographic Institution (OSB survey).

physics and physical oceanography. This statement is less true for the biological sciences. If the same comparison is made for just Scripps Institution of Oceanography (SIO) and Woods Hole Oceanographic Institution (WHOI), the two largest oceanographic institutions, their combined dominance in terms of percentage of faculty has decreased steadily over the past 20 years (Figure 4-13), except in marine engineering. So although the percentage of total oceanography faculty at the two largest oceanographic institutions has decreased over the past two decades, the percentage of total oceanography faculty at the ten largest has remained about the same.

JOI provided information on its institutions' students, graduates, and faculty. The number of ocean science doctorates awarded annually at JOI institutions increased from 90 in 1970 to 126 in 1991 (Figure 4-14). The major change is the large increase in the number of women earning doctorates in the ocean sciences, up from 10 percent in 1980 to almost 30 percent in 1991. The number of foreign students earning doctorates is also about 30 percent; 2.5 percent of JOI students are underrepresented minorities.

The median age of oceanographers who received NSF grants increased from 40 in 1977 to 45 in 1990. The median age of JOI faculty was 44 years in 1990 (Figure 4-15).

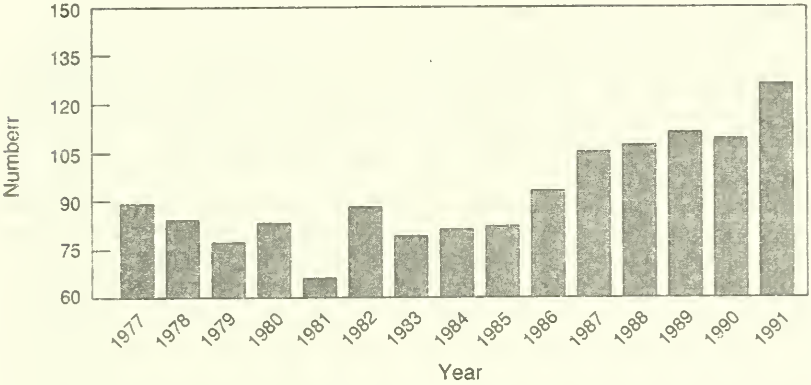


FIGURE 4-14 Number of Ph.D.s awarded annually at JOI institutions.

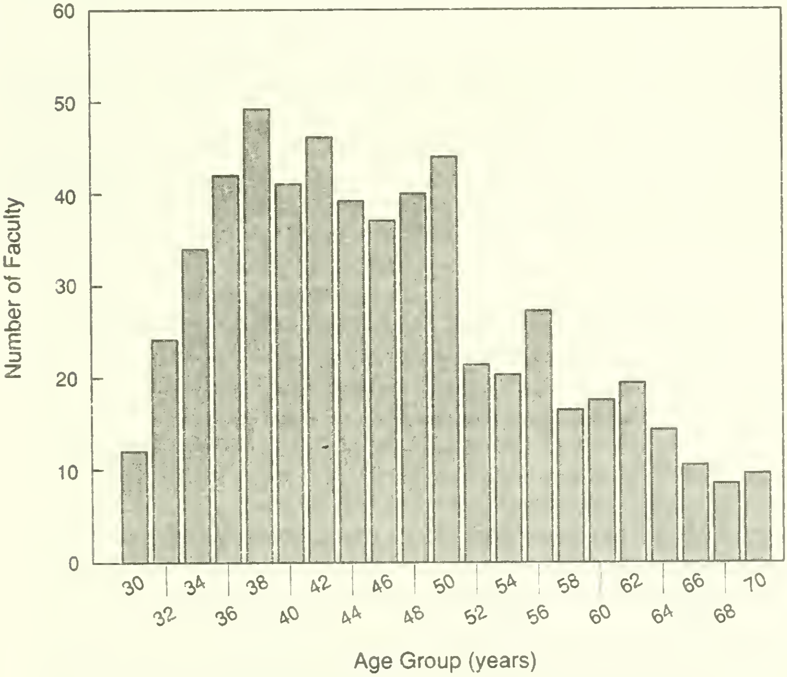


FIGURE 4-15 Age distribution of Ph.D.-level staff at JOI institutions in 1990.

Demand from the Major Programs

The extra demand required for the major ocean science initiatives planned for the 1990s is difficult to estimate. It is possible to estimate how many ocean scientists the major programs will require if the programs are funded at the projected levels, but the number of participants who are already in the field is an unknown. Because oceanography continues to attract scientists from physics, chemistry, biology, and geology, entry points into the field vary from the undergraduate to the postdoctoral level. Thus demand can often be met from associated fields. Nonetheless, it is of interest to estimate the impacts of four major oceanographic initiatives on human resources. The requirements of the programs were estimated by the individual program offices and represent a maximum level under a scenario of full funding and the assumption that the programs retain their original scopes and timetables.

The U.S. office for the World Ocean Circulation Experiment (WOCE) has estimated the work force that will be required to carry out its planned experiments for 1990–2000 (Table 4-3). The figures were extrapolated from NSF-funded project proposals. The total principal investigator (PI) and postdoctoral fellow labor-months estimated for the U.S. part of WOCE is 8,189, of a total of 28,507 (30 percent). The U.S. office for the Joint Global Ocean Flux Study (JGOFS) estimated a requirement of 14,000 labor-months for all categories from 1990 to 2000. If it is assumed that roughly

TABLE 4-3 Estimated Demand for Ph.D.s for Major Ocean Science Research Programs (1990–2000)

	Person-Years[a]	
Program	All Ph.D.-Level Oceanographers	Postdoctoral Oceanographers
WOCE	1,000	320
JGOFS[b]	720	160
RIDGE[b]	200	40
GLOBEC	1,100	440
Total	3,020	960

[a] Assumes 6 person-months per year for 10 years.

[b] Assumes that JGOFS and RIDGE have the same ratio of PI and postdoctoral labor-months:total man-months (30%) as WOCE.

the same percentage of the total labor-months for WOCE scientists and postdocs should be valid for JGOFS, then JGOFS will require an estimated 4,300 labor-months (0.3 × 14,400) in this decade. The Ridge Inter-Disciplinary Global Experiment (RIDGE) office estimates it needs 4,000 labor-months over the 1990–2000 decade, and the Global Ocean Ecosystems Dynamics (GLOBEC) program has estimated 6,600 labor-months at the PI and postdoctoral levels. If 6 labor-months per labor-year are assumed, equal annual effort over the decade, and full program funding are assumed, approximately 300 Ph.D.s will be required to carry out WOCE, JGOFS, GLOBEC, and RIDGE. Of these, 100 will be at the postdoctoral level. If only 50 percent of the average oceanographer's labor-months are available for research, about 22 percent of the 1990 academic oceanographer pool would be needed for these four programs, if they are fully funded.

Answering Specific Questions

How many Ph.D.-level oceanographers are there and at what rate has the number of Ph.D.-level ocean scientists changed over time? According to the OSB survey, there were 1,674 academic oceanographers and 516 federal oceanographers in 1990. The NSF survey (1989) estimated 1,354 academic oceanographers, 453 federally employed oceanographers, and 653 Ph.D.-level oceanographers in other sectors.

The growth rate in the number of Ph.D.-level oceanographers slowed from the 1970s to the 1980s. Average annual growth rates for the pool of academic oceanographers decreased from 4.7 to 4.0 percent according to NSF surveys, and from 6.4 to 2.6 percent according to the OSB survey. The slowing of growth was even more evident for the federal government.

How many ocean science doctorates are produced annually? The JOI data show that approximately 126 oceanography Ph.D.s were awarded from JOI institutions in 1991, which is the largest number in any year for which data are available.

What is the present age profile of oceanographers in academia and the federal government, and has it changed over time? The OSB survey measured a median age in the 40- to 50-year-old bracket for both academic and federally employed oceanographers. The JOI faculty age distribution shows a median of approximately 44 years. The median age of the field has increased over the past 20 years from the 35- to 39-year-old bracket to the 40- to 44-year-old bracket, according to the NSF survey. In addition, the median age of NSF Ocean Sciences Division grantees increased from 40 years in 1977 to 45 years in 1990.

Has the field matured in terms of becoming a separate discipline? Over the past 20 years, the field has matured according to several measures. The expansion of postdoctoral positions shown by both the NSF and the OSB surveys, and the increase in the ratio of full to assistant professors are both indicators of the field's maturing. The significance of changes in the faculty ratio is uncertain, however, because the ratio for the combined science and engineering fields has also increased, and the 1989 jump in ratios for oceanographers is difficult to explain. The lag of female faculty behind the rest of the field may be because of the relatively recent entry of women into the field.

Has the participation of women, minorities, and foreign nationals changed over time? The percentage of women in the field of oceanography increased from 4 to 11 percent from 1973 to 1989, according to the NSF survey. At present, 30 percent of students at JOI institutions are women. The percentage of underrepresented minorities is low in both the population of employed oceanographers (7.7 percent) and the JOI student population (2.5 percent). The percentage of oceanographers working in the United States who are foreign nationals did not change dramatically from 1973 to 1989.

Has the field changed in terms of emphasis among the differing major subdisciplines (physical oceanography, chemical oceanography, marine geology and geophysics, biological oceanography and marine biology, and ocean engineering)? The relative balance of the number of scientists in the academic disciplines has changed little in the past 20 years. For federally employed scientists, fewer are biologists and more are specialists in physical oceanography and marine geology and geophysics now than in 1970.

Has the balance of the field changed in terms of the relative size and importance of the major oceanographic institutions? This analysis documents the fact that some decentralization of the field has occurred over the past 20 years in terms of where Ph.D-level scientists are employed. During and after World War II, Navy and NSF support led to the expansion of JOI institutions. In 1970, the faculty at SIO and WHOI constituted approximately 40 percent of the field. By 1990, the faculty at these two institutions comprised only about 25 percent of the total. The distribution of scientists at JOI institutions differed by subdiscipline, correlating with sciences that tend to require large ships, such as physical oceanography and marine geology and geophysics. In terms of financial support from NSF, JOI institutions received a relatively

TABLE 4-4 Support of Ocean Science Faculty at Academic Institutions

	Number of Months of Institutional Support	
Faculty Position	JOI Schools	Non-JOI Schools
Full professor/scientist	7.3 ± 1.0 (n = 8)	8.5 ± 0.5 (n = 23)
Associate professor/scientist	5.5 ± 0.9 (n = 8)	7.8 ± 0.6 (n = 23)
Assistant professor/scientist	4.9 ± 1.1 (n = 8)	7.7 ± 0.6 (n = 28)

NOTE: n = the number of institutions responding. It is assumed that each institutional response is the average of that institution's professionals.

constant 45 percent of NSF ocean science research funding between 1984 and 1989. JOI institutions received about 40 percent of ONR funding (SE31 and SE32).

How are research oceanographers supported? What is the ratio of institutional to federal salary support for the oceanography community as a whole? Oceanographers' salaries come primarily from grants and contracts. Academics from JOI institutions must raise a significantly greater proportion of their funding from external sources than other academics. The OSB survey shows that most of the oceanographic community, especially JOI schools, depends on noninstitutional research support (Table 4-4).

PHYSICAL RESOURCES

The wide variety of facilities used in institutions and consortia for ocean science—ships, submersibles, satellites, special platforms, and laboratories—depends on continual renewal to meet present and future needs. Global change research has given new impetus to satellite data systems and large-scale at-sea programs. Although oceanographers learned to use satellite data in the past decade, incorporating the increasing stream of data from new satellites and platforms will be a technological and managerial challenge.

Oceanographic Institutions

From its beginning, a mix of government, university, and private laboratories has conducted oceanographic research. The history of our ocean science institutions is characterized by three phases. Civilian marine science began in the late 1800s with the establishment of several marine biological laboratories concerned principally with coastal problems. The California Academy of Sciences (1853), the U.S. Fish and Wildlife Biological Laboratory at Woods Hole (1885), Hopkins Marine Station of Stanford University (1892), and the Hydrobiological Laboratory of the University of Wisconsin (1896) were notable among the early laboratories.

Between the turn of the century and the end of World War II, both the number of ocean science laboratories and the disciplinary range of their activities grew. During this period, Scripps Institution of Oceanography (1903), Friday Harbor Laboratories of the University of Washington (1904), Woods Hole Oceanographic Institution (1930), Narragansett Laboratory of the University of Rhode Island (1930), Bingham Oceanographic Foundation of the University of Southern California (1940), the Virginia Institute of Marine Science (1941), and the University of Miami Marine Laboratory (1943) were established. Several of these laboratories continued the thrust of activity in coastal marine biology, and many expanded into physical, chemical, and geological oceanography and increasingly carried out research in the open ocean.

World War II was a major turning point in oceanography. Research on ocean processes begun during the war continued afterwards as basic research programs supported by the newly created Office of Naval Research. Additional ships were added to the oceanographic fleet, and support for both research and ship operations was readily available. Under the Navy's leadership during the postwar period, growth in the number of ocean institutions and their scope of research accelerated. Thus from the late 1940s to the early 1950s, several laboratories, most of which would eventually engage in deep-ocean research, were established or expanded. Among the new institutions were the Chesapeake Bay Institution of the Johns Hopkins University (1948), Florida State University Oceanographic Institute (1949), the Department of Oceanography of Texas A&M University (1949), the University of Delaware Marine Laboratories (1951), the Department of Oceanography of the University of Washington (1951); the Department of Oceanography of Oregon State University (1958), and the University of Hawaii Institute of Geophysics (1959).

In the early years of marine science, there were no formal mechanisms for coordinating institutions' activities. The Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES), an international advisory committee, was established in the late 1960s to provide formal advice to the Deep Sea Drilling Project (DSDP). JOIDES was a major initiative by the oceanographic community to develop a mechanism for international cooperative activities. Evolving from JOIDES was JOI, a formal not-for-profit corporation. JOI consists of 10 U.S. ocean science institutions that operate many of the large ships in the oceanographic fleet, employ a majority of U.S. academic ocean scientists, and receive a majority of the research funding. The JOI institutions are

Scripps Institution of Oceanography, University of California
Lamont-Doherty Geological Observatory, Columbia University
School of Ocean and Earth Science and Technology, University of Hawaii
Rosenstiel School of Marine and Atmospheric Sciences, University of Miami
College of Oceanography, Oregon State University
Graduate School of Oceanography, University of Rhode Island
College of Geosciences and Maritime Studies, Texas A&M University
Institute for Geophysics, University of Texas
College of Ocean and Fisheries Sciences, University of Washington
Woods Hole Oceanographic Institution

With the exception of Woods Hole, which has a joint education program with the Massachusetts Institution of Technology (MIT), each oceanographic program is an integral part of a major university.

Another cooperative organization of oceanographic institutions is the University-National Oceanographic Laboratory System (UNOLS), an association of ship operators and ship users that is discussed in more detail below. Because UNOLS provides access to facilities for scientists at institutions without ships, an increased number of universities can be involved in open ocean research. These universities may not have interests in all facets of oceanography, but they have significant strengths in certain areas. Examples of such universities are the Santa Cruz and Santa Barbara campuses of the University of California, Northwestern University, Massachusetts Institute of Technology, and Princeton University.

The institutions developed within and outside the government for the pursuit of an understanding of the ocean are diverse, much more so than in most other scientific fields. Oceanography is conducted by individuals working as faculty members in conventional academic Earth sciences departments supported by state and private endowment funds (e.g., MIT, Florida State University, the University of Michigan) in large research institutions operated by universities, but on a scale not common to academic institutions (e.g., Scripps Institution of Oceanography, Lamont-Doherty Geological Observatory), in independent, private nonuniversity organizations (e.g., Woods Hole Oceanographic Institution, Boothbay Harbor Laboratories, Monterey Bay Aquarium Research Institute); in government laboratories resembling the private laboratories in many ways (the National Oceanic and Atmospheric Administration Atlantic Oceanographic and Meteorological Laboratories and Pacific Marine Environmental Laboratories); and in Navy laboratories charged with specific military responsibilities.

This diversity is both a potential weakness and a strength. Oceanographers are generally more dependent on grant money than are scientists in other disciplines who receive a higher percentage of support from their universities. On one hand, this situation renders ocean science more vulnerable to government budget fluctuations. However, the institutions are adaptable to changes in the conduct of ocean science. Some institutions are expert in seagoing observations, some specialize in ocean engineering, some are focused on large-scale numerical modeling, and others are best known for their breadth. Together, they comprise the strongest marine research establishment in the world.

Most oceanography degrees are offered at the graduate level; however, an increasing number of institutions are now offering undergraduate degrees in oceanography. Integration of marine research facilities (often isolated from the campus) into the academic structure of the parent university is improving, and new oceanography programs have developed within a more traditional academic departmental structure. Perhaps this change can be considered an indicator of the maturing of oceanography as a recognized academic discipline.

Several new organizations of ocean science institutions have recently formed, such as the Council on Ocean Affairs (COA) and the National Association of Marine Laboratories, to promote interlaboratory cooperation. COA is an organization of approximately 50 academic oceanographic institutions that was founded by, and is administratively housed in, Joint Oceanographic Institutions, Inc.

Thus, with increased ease of access to the sea for faculty and students, the establishment of more oceanography activities in universities, and substantial support by some universities, oceanography is becoming an established academic discipline. Physical resource requirements to ensure that the levels of support, equipment, and access to the ocean are adequate to carry out the research needed in the next decade should be important principles as academic institutions and federal agencies develop new partnerships.

Ships

Even with new remote sensing techniques and autonomous vehicles, ships will continue to be the major platform for direct at-sea observations and measurements as well as for the calibration and verification of remote measurements. These tasks require a modern fleet of research vessels, a fleet whose composition and capabilities should be tailored to research objectives.

The federal oceanographic fleet is defined as the set of oceanographic vessels whose operations are funded by the federal government. The fleet is composed of more than 60 vessels operated by both federal agencies and academic institutions. The academic institutions coordinate their ship activities through UNOLS, which was formed in 1971 to support oceanographic research by coordinating and scheduling ships and equipment for their efficient use. UNOLS institutions operate and use vessels owned by the NSF, the Navy, and academic institutions. The UNOLS fleet, although not formally designated as a national facility, is recognized as a national asset vital to the needs of U.S. oceangoing scientists. Before the formation of UNOLS, each institution negotiated separately with the group of federal supporters. Ships were scheduled primarily for the exclusive use of the operating institution's scientists. UNOLS's consolidated scheduling of ships has improved efficiency and ensured availability of time at sea to all funded researchers. Its success has reduced the importance of each institution's operating its own research vessel and has allowed, from a national viewpoint, institutions without ships to develop strong marine programs with seagoing components.

UNOLS consists of 57 member institutions, of which 20 operate research vessels. The UNOLS fleet is composed of surface ships ranging in length, age, and origin; the submersible *Alvin*; and the floating instrument platform (FLIP) (Table 4-5). Some were built using capital provided by the federal government; others were built or purchased at state or institutional expense. In 1990, NSF supported 59.0 percent of UNOLS's operational ship days; ONR's contribution was 15.5 percent; other federal agencies

TABLE 4-5 UNOLS Fleet

Name of Ship	Length (feet)	Built/Refit (year)	Total Ship Days (1990)
Knorr	279	1970/1991	N/A
Melville	279	1969/1992	N/A
Thompson	274	1991	N/A
Ewing	239	1983/1990	201
Vickers	220	1973/1989	N/A
Moana Wave	210	1973/1984	275
Atlantis II	210	1963	283
Wecoma	177	1975	157
Endeavor	177	1976	221
Oceanus	177	1975	239
Seward Johnson	176	1984	176
Gyre	174	1973/1980	216
New Horizon	170	1978	233
Columbus Iselin	170	1972	279
Edwin Link	168	1982/1988	107
Point Sur	135	1981	177
Cape Hatteras	135	1981	175
Alpha Helix	133	1966	109
R.G. Sproul	125	1981/1985	119
Cape Henlopen	120	1976	59
Pelican	105	1985	121
Laurentian	80	1974	148
Longhorn	80	1971/1986	53
Blue Fin	72	1972/1975	71
C.A. Barnes	65	1966/1984	154
Calanus	64	1971	93
Total ship days (1990)			4,066
Total days for ships >150 feet in length			2,680
AGOR-24	274 (planned)	?	N/A
AGOR-25	274 (planned)	?	N/A
FLIP	355	1962	65
DSRV *Alvin*		1964	241

NOTE: N/A = Not applicable; AGOR = Auxiliary General Oceanographic Research; DSRV = Deep Submergence Research Vehicle

contributed 8.6 percent; state municipalities, 10.0 percent; and foreign and private users, 6.9 percent (UNOLS, 1991). NSF's share of total funding of sea days has increased over time (Figure 4-16). The average age of the UNOLS fleet is 16.5 years (Figure 4-17). For fiscal year 1992, the total ship operations budget was about $50 million, with a larger ship costing about $15,000 per day to

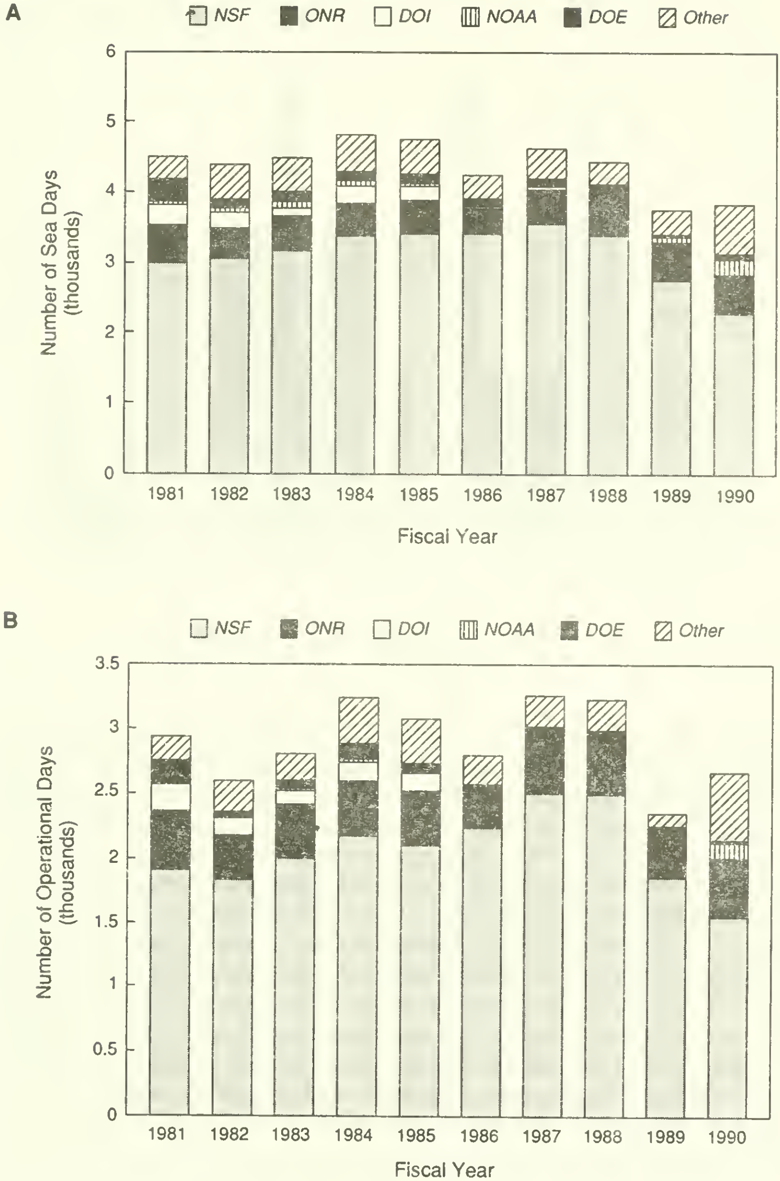


FIGURE 4-16 (A) UNOLS ship day funding by agency (all ships). From UNOLS, 1991. (B) UNOLS ship day funding by agency (ships >150 feet long). From UNOLS, 1991.

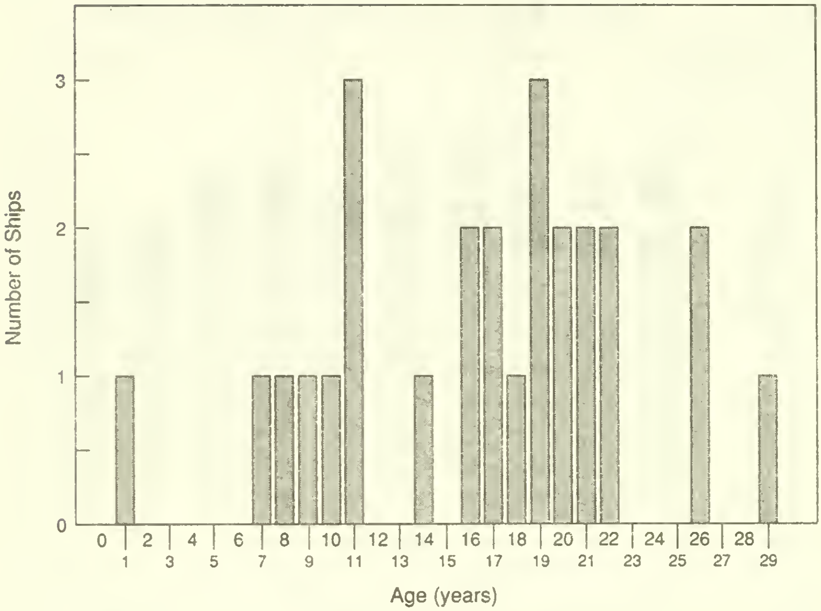


FIGURE 4-17 Age of UNOLS ships from time originally built.

operate. In addition to the UNOLS fleet, smaller vessels used primarily for coastal research are funded principally by local sources.

Federal agencies that either operate or fund oceanographic ships include the U.S. Coast Guard (USCG), the U.S. Geological Survey (USGS) and the Minerals Management Service (MMS) of the Department of the Interior (DOI), the Environmental Protection Agency (EPA), the Department of Energy (DOE), the Naval Oceanographic Office, the Office of Naval Research, the National Oceanic and Atmospheric Administration, and the National Science Foundation. The USCG is included because its two icebreakers can support research operations in the Antarctic and Arctic. The need for and operation of federal oceanographic ships arise from the statutory mission of each agency that is manifested by approved and funded programs in the federal budget. Individual agency programs dictate the requirements for ships and ship time. The federal fleet is older, on average, than the UNOLS fleet (Figure 4-18).

Ship use by different oceanography subdisciplines during the 1980s is shown in Figure 4-19. For all ships, biological oceanography uses the most ship time. For the larger ships, marine geology

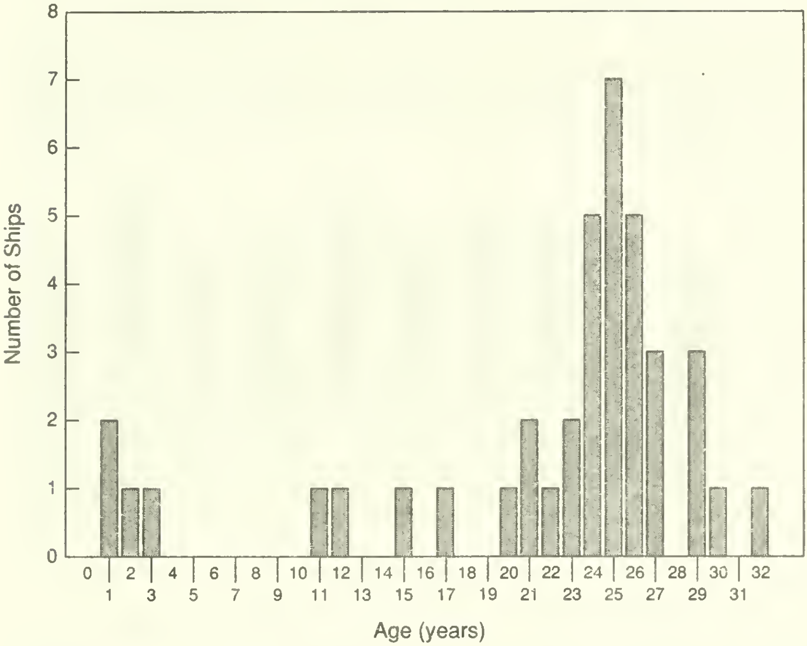


FIGURE 4-18 Age of federal oceanographic fleet.

and geophysics has the most ship days, followed by physical oceanography. The pattern of use, particularly for ships more than 150 feet long, is remarkably stable and probably indicates the future use of ships (Figure 4-19).

As discussed in earlier chapters, a significant development in oceanography is the increased number of large, long-term research activities planned by the academic oceanographic community. These include the Tropical Ocean-Global Atmosphere (TOGA) program, WOCE, JGOFS, and RIDGE. These major programs account for significant use of the larger ships.

Present trends suggest that research in coastal oceanography will continue to be important over the next decade because it is the primary interest of most federal mission agencies, states, and municipalities. Although some future coastal research efforts will be well served by some of the existing research vessels (*Oceanus* or *Cape* class), smaller research vessels are also needed. Specifically, these new vessels should be capable of working at sea for up to 20 days at a time, at a cost of about $3,000 per day, and their

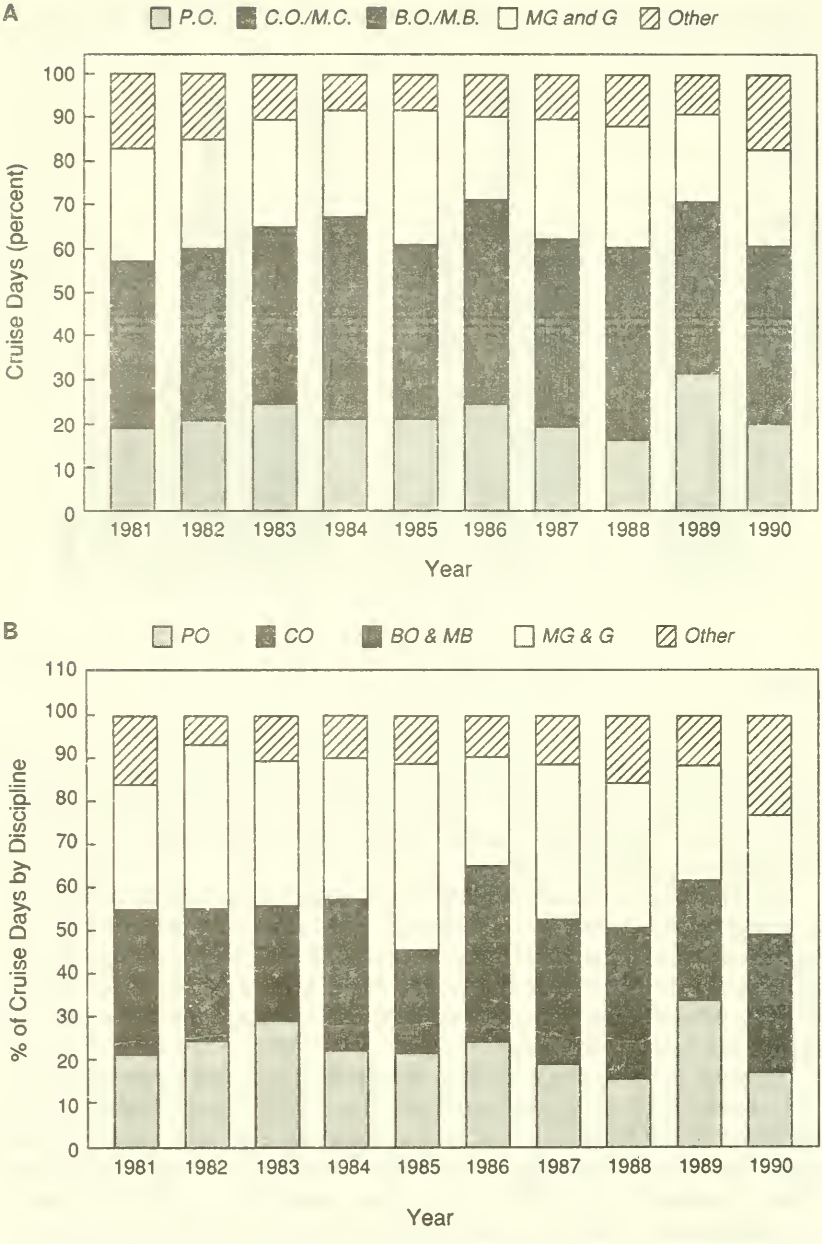


FIGURE 4-19 (A) Cruise days funded, by discipline (all UNOLS ships). (B) Cruise days funded, by discipline (UNOLS ships >150 feet long).

scheduling should be flexible. A few UNOLS vessels satisfy these criteria. Present estimates are that a vessel designed for coastal oceanography would cost $12 million to build and equip. At least one group of institutions is proceeding independently to design its own ship in this class. UNOLS is cognizant of the need for a coordinated plan to reduce any redundant effort concerning new coastal research ships.

Special Facilities

Submersibles

A broad range of submersible systems is available from the government or can be leased commercially. Since 1964 the *Alvin*, capable of operating to a depth of 4,000 meters, has given scientists a presence in the deep sea. *Alvin* is valuable to scientists who conduct research in the water column or study processes at the seawater-seafloor boundary. WHOI operates *Alvin* as a national facility, with sponsorship by an interagency agreement among NOAA, ONR, and NSF.

The Navy (Submarine Development Group One) operates the *Sea Cliff* (capable to 6,000 meters) and *Turtle* (to 3,000 meters) in support of Navy operations and research. *Sea Cliff* and *Turtle* have been used minimally by the academic community. *Sea Cliff* is the only U.S. submersible available to scientists that can operate at depths to 6,000 meters. An agreement among the Navy, NOAA, and UNOLS will improve the coordination and use of Navy deep submergence assets for academic research. Harbor Branch Oceanographic Institution owns and operates two Johnson Sea Link (1,000 meters) submersibles, which have been used intensively by academic researchers, government, and industry.

Unmanned, tethered, remotely operated vehicles (ROVs), which for some time performed ocean engineering tasks largely for the offshore oil industry, appear to be gaining acceptance and use by ocean researchers. Some ROVs are less expensive than manned submersibles and allow long submerged endurance times, making them attractive tools for some tasks vis-à-vis manned submersibles.

Floating Instrument Platform

The Floating Instrument Platform (*FLIP*), operated by SIO, fills scientific needs for a stable platform in rolling seas. It has been used for studying acoustic signals, surface and internal wave properties, and water temperature, and for collecting meteorological data. *FLIP* achieves its stability and vertical access through the water column by its extension vertically below the surface when on station. Increased efforts to improve active acoustic capabilities and all-weather operations in higher latitudes emphasize the continuing requirements for a *FLIP*-like platform. The present *FLIP* cannot support the more demanding projects expected in the near future. Research users have requested a second-generation *FLIP* that would allow for deployment of new larger, multidimensional acoustic arrays, ROVs, and other equipment under development.

JOIDES Resolution

The *JOIDES Resolution* is a specially equipped drilling vessel that has laboratory facilities for studying core samples and the capability for making downhole measurements (logging). NSF has contracted with JOI, which has in turn contracted with Texas A&M University to serve as science operator and with Lamont-Doherty Geological Observatory to provide logging and other services. The science operator is responsible for the operation of the drill ship, cruise staffing, logistics, engineering, shipboard laboratories, archiving of core samples and data, and publications. The Ocean Drilling Program is in the category of large science projects that require the application of expensive state-of-the-art technology for the advancement of the science.

Satellites: Ocean-Related Remote Sensing

In the early 1980s, NASA asked JOI to prepare a report on satellite oceanography. The report—*Oceanography from Space 1985–1995* (JOI, 1985), prepared by a committee of oceanographers expert in the field, recommended a series of ocean-related remote sensing missions that are scheduled for the 1990s (Table 4-6). It is increasingly clear that understanding the ocean is central to global change research and that the National Aeronautics and Space Administration (NASA) and analogous space agencies around the world should be major participants in the development of ocean remote sensing. Although several ocean-related missions are scheduled in the early 1990s, plans for the late 1990s and beyond are still tentative. Because of the long lead time from the concept of a satellite sensor until it is launched, efforts are needed now to ensure the development of relevant missions for the early twenty-first century to avoid gaps in time series of important measure-

TABLE 4-6 Status of Major, Pre-EOS Ocean Spacecraft and Instruments (as of fall, 1991)[a]

Satellite	Sponsor	Instruments	Launch Date
DMSP Series	USAF NASA[b]	MR	June 1987
Polar Series	NOAA NASA[b]	IR	Ongoing
ESA ERS-1	ESA NASA[b]	ALT, SCAT, SAR IR	July 1991
NASDA ERS-1	NASDA NASA[b]	SAR	February 1992
TOPEX/Poseidon	NASA CNES	ALT	July 1992
SeaWiFS	OSC NASA[b]	CS	August 1993
ESA ERS-2	ESA	ALT, SCAT, SAR IR	1994+
RADARSAT	CANADA NASA[b]	SAR	Late 1994
ADEOS	NASDA NASA[b]	SCAT, CS	1995

NOTE: ALT = radar altimeter; CNES = French space agency; CS = color scanner; ESA = European Space Agency; IR = infrared radiometer; MR = microwave radiometer; NASDA = Japanese space agency; OSC = Orbital Sciences Corporation; SAR = synthetic aperture radar; SCAT = scatterometer; SeaWiFS = Sea viewing Wide Field Sensor.

[a] EOS = Earth Observing System.

[b] Provides data or other services to U.S. research users.

ments and deterioration of U.S. capabilities. The advancement of ocean science depends on both general Earth-observing and ocean-specific missions. The continuance and strengthening of partnerships between NASA and other agencies and with industry in the United States and abroad are key to the success of ocean-related missions.

Satellite observations contribute to studies of sea surface waves, wind speed and direction, gas fluxes, atmospheric water vapor concentrations and rainfall, sea surface temperature, ocean color, sea ice distributions, ocean surface topography, and gravity. The potential of satellite oceanography is almost unlimited, although its usefulness for most purposes depends on in situ calibration of the remote measurements.

Atmospheric water vapor must be measured because it is used in computing ocean surface evaporation and thermal forcing and is needed to correct altimetry data. Sea surface temperature observed by infrared sensors is the surface signature of ocean temperature changes. It is a vital parameter in estimating surface heat fluxes and evaporation, and can be used to infer some circulation features.

Remote sensing of ocean color is a key element for understanding the global ocean carbon budget. To obtain long-term continuous global ocean color measurements, the Sea-viewing Wide Field Sensor (SeaWiFS) sensor will be launched on a satellite in 1993. Future ocean color instruments should include improvements in spectral coverage and calibration. An ocean color sensor and scatterometer should be combined on a future satellite because of the close connection between wind stress and productivity. With future sensors, data from more wavelengths may be collected. This should allow estimation of various colored dissolved organic materials and, perhaps, separation of phytoplankton pigment groups. Sun-stimulated fluorescence at 683 nanometers (Chamberlin et al., 1990) may be a good indicator of the photosynthetic state of the phytoplankton and thus be useful in improving primary productivity models.

Passive microwave sensors measure concentrations of open water versus sea ice and may, in the future, be able to estimate the emitting temperature of the upper layer of the ice, which is related to the surface heat balance. The large-scale shape of the ocean surface (the geoid) is primarily related to Earth's gravity field because the ocean surface tends to form a level surface perpendicular to the force of gravity at any given location. Deviations from this level surface are caused primarily by ocean currents. Ocean currents can be studied by a combination of altimeter measurements of the ocean surface height and gravity measurements of the geoid.

Precise satellite geodetic measurements, providing information on crustal deformation, continental drift, and plate tectonics, Earth and ocean tides, and changes in Earth's geopotential, have been carried out since 1976 in a joint project between the United States and Italy with the Laser Geodynamics Satellite.

A mission to determine Earth's gravity field is still needed. No gravity mission is firmly in any space agency's plans, but design studies are being conducted. Of particular interest are the joint U.S./ESA (European Space Agency) plans for a gravity mission called Applications and Research Involving Space Technologies Observing the Earth's Field from Low Earth Orbiting Satellites (ARISTOTELES). The ARISTOTELES spacecraft would include both a gravity gradiometer for highly accurate gravity measurements and a magnetometer for geomagnetic studies. It is important that the geomagnetic mission begin before 1998 to avoid the next sunspot maximum, which would hamper the low-altitude initial portion of the satellite's mission.

It is clear from Table 4-6 that many objectives of the original *Space, A Research Strategy for the Decade 1985–1995* (JOI, 1985) report are being met. Yet successful completion of many missions requires more than just NASA support; new partnerships are needed. Healthy relationships between U.S. and non-U.S. space agencies and with private industry are also needed. Some of these relationships appear to be working well, for example, in Earth Resources Satellite-1 data sharing through the Alaska synthetic aperture radar facility and in the joint design of TOPEX/Poseidon with the French. Future partnerships, such as those in ocean color with the Orbital Sciences Corporation's SeaWiFS, are yet to be tested. It is clear that developing and maintaining these partnerships require strong leadership at NASA headquarters, so that U.S. participation in the process from sensor design to data analysis is guaranteed. The oceanographic community must not find itself wholly dependent on international agreements and data from non-U.S. sensors and missions during the late 1990s and beyond.

There is a need for continuing research in the development of mathematical techniques to correct satellite data for the effects of clouds, water vapor, and other atmospheric aerosols, to relate satellite measurements to observations at the ocean surface, and to relate the surface signal to processes occurring at depth. If calibration errors in the satellite data time series can be avoided, it will be possible to create a time series that is long enough to investigate low-frequency phenomena in the record of upper ocean temperatures and other variables.

Numerical Ocean Modeling

Numerical ocean modeling has reached a degree of sophistication whereby it can affect the study of present ocean circulation and the prediction of future climate. Relatively realistic multidecadal simulations of the North Atlantic, the Southern Ocean, and the world ocean have recently been carried out. The results of these experiments are being analyzed by numerous groups to aid in understanding the ocean general circulation (e.g., Boning et al., 1991; Semtner and Chervin, 1992). Data collected by comprehensive field programs such as WOCE and TOGA can be interpreted better through the use of realistic models, and field data provide essential tests for the models. WOCE is sponsoring a community modeling effort whereby different models of global circulation are compared. Overall scientific progress is maximized by the interaction of models and observations.

Future progress in modeling will involve new techniques and significantly faster computers to conduct simulations with more realistic hydrodynamics, improved resolution of eddies, longer time integration, and more testing of methods of handling subgrid-scale variables.

Technological advances will probably enhance ocean modeling more than changes in methodology. Computers are expected to attain speeds in excess of one trillion floating-point operations per second (a teraflop) before the year 2000. This thousandfold improvement over computers of 1990 will allow major improvements in simulation capability, such that realistic global models might be achieved. Their maximal use will require the development of highly parallel algorithms. Because most ocean models are formulated in terms of local space-time processes, they should be easily implemented on massively parallel computers.

The computer and communications requirements for archiving, analyzing, and visualizing the output of eddy-resolving basin- to global-scale models are vast. Ongoing federal programs in high-performance computing should help to develop some of the necessary resources. Ocean modeling was highlighted as one application of high-performance computing in the interagency Federal Coordinating Council for Science, Engineering, and Technology supplement to the president's budget for fiscal year 1993 (FCCSET, 1992). Also, large observational programs are critical because basin- to global-scale, long-term ocean data sets are required to initiate and validate ocean models.

FISCAL RESOURCES

Information on oceanographic research funding in the United States for the 11 fiscal years from 1982 to 1992 is compiled here.

NSF and ONR provide the majority of federal support for university-based basic oceanographic research. In addition, several federal mission agencies (i.e., NOAA, NASA, USGS, MMS, DOE, and EPA) support ocean science research both within their agencies and through extramural funding to the academic research community.

Federal Funding of Ocean Science

This section describes federal support of ocean science; it does not include funding by states and the private sector. For most of the mission agencies, no distinction is made between basic research conducted in a federal laboratory and that supported at universities, but for NASA, university science support is separated from total science support.

Uniform budget information for all these agencies is difficult to obtain because some agencies reorganized during fiscal years 1982–1992, and ocean and nonocean research budgets are sometimes combined into one budget category. Yearly funding is presented by agency in both current dollars (Table 4-7) and constant 1982 dollars (Table 4-8). The funding data were substantiated by the agencies for accuracy within ±5 percent. The inflation adjustment to constant dollars is based on the gross national product (GNP) index for the years 1982–1992. The GNP indices used for 1990–1992 are estimates.

The distribution of fiscal year 1992 support for basic research is shown in Figure 4-20. NSF was the largest supporter of basic oceanographic research in the United States (34.5 percent) and, along with ONR (20.4 percent) and NOAA (16.1 percent), provided more than 70 percent of the reported support in fiscal year 1992. NOAA's ocean science research programs (including Sea Grant) were funded at about the same level as the ONR program, and other federal agencies, including USGS, EPA, NASA, and MMS, have significant programs in ocean-related research. Thus to obtain a comprehensive picture of funding trends, contributions from these other federal agencies must be included.

National Science Foundation

Since the 1960s, NSF has been the principal supporter of academic oceanographers in the United States. Figure 4-21 shows the growth of the overall NSF budget and the ocean science component for fiscal years 1982–1992 in both current and constant

TABLE 4-7 Ocean Science Federal Agency Budget History: Current Dollars (millions)

Agency	Fiscal Years 1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
ONR total SE 31 and 32[a]	71.0	65.9	65.8	70.2	64.2	79.2	87.4	89.3	88.1	105.0	106.0
SE 31 ocean science	35.5	37.2	39.4	39.3	41.7	50.9	56.7	52.3	52.0	60.7	58.6
SE 32 ocean geophysics	27.5	28.1	27.7	26.2	29.2	29.2	32.1	36.1	36.1	36.2	40.9
SE 33-03 marine meteorology	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.5
Total NSF (overall)	995.6	1,093.5	1,322.6	1,501.6	1,458.3	1,622.9	1,717.0	1,923.2	2,078.8	2,366.0	2,573.0
NSF (total ocean science)[a]	95.0	102.5	114.3	121.2	119.4	133.7	135.0	145.9	147.4	164.7	178.8
OSRS	46.4	49.9	55.1	58.3	56.9	66.5	67.2	70.9	72.9	82.0	90.8
B.O.	10.7	11.8	12.9	13.9	13.3	14.4	14.8	17.1	17.3	20.3	23.1
C.O.	10.1	10.8	12.0	12.4	11.9	13.4	13.7	14.5	14.9	16.1	17.4
MG and G	12.0	12.6	14.6	15.2	14.6	16.2	16.2	16.0	16.0	17.4	19.2
P.O.	13.7	14.7	15.6	16.8	17.1	22.5	22.8	23.3	24.7	28.3	31.1
DSDP/ODP (total)	20.5	21.0	26.3	27.7	28.8	30.0	30.6	31.4	32.0	35.0	36.4
OCF	28.1	31.6	32.9	35.2	33.7	37.2	37.2	43.6	42.5	47.7	51.6
NOAA (total ocean science)[a]	117.9	133.7	91.5	83.7	86.5	75.5	73.3	80.8	81.7	84.5	83.6
Sea Grant	22.5	22.8	23.5	25.0	25.7	25.9	25.4	24.8	27.2	25.3	31.8
Global Change	—	—	—	—	—	—	—	5.4	9.5	21.2	21.2
Coastal Ocean Program	—	—	—	—	—	—	—	—	6.4	10.8	11.5
DOE (total ocean science)[a]	14.6	7.1	9.3	9.4	7.7	7.3	6.8	8.9	10.1	10.3	12.2
Oceans Research	9.9	5.0	6.6	6.7	5.0	5.4	5.1	5.8	5.8	4.5	5.5
Global Change	4.7	2.1	2.7	2.7	2.7	1.9	1.7	3.2	4.3	5.8	6.7

USGS[a]	21.9	13.0	18.6	21.5	25.3	26.0	28.5	29.5	32.4	37.7	36.7
MMS[a]	27.1	30.2	25.3	23.8	19.7	18.7	19.1	17.0	17.1	25.1	15.0
EPA[a]	NA	NA	NA	NA	NA	NA	NA	16.2	21.1	35.5	49.2
NASA (total ocean science)[ab]	16.6	17.5	18.7	20.5	22.2	23.2	23.7	25.3	26.7	31.1	36.5
(including satellites)	17.4	19.1	20.6	33.7	38.0	61.0	115.6	110.5	137.7	133.8	139.4
Research and analysis[b]	16.2	17.0	18.2	19.7	20.6	20.8	21.0	22.3	22.4	25.3	26.4
University science	3.3	4.0	3.8	5.4	4.0	5.5	7.1	8.0	11.5	12.3	12.6
Flight projects total	1.2	2.1	2.4	14.0	17.4	40.2	94.6	88.2	115.3	108.5	113.0
Total nonscience	0.8	1.6	1.9	13.2	15.8	37.8	91.9	85.2	111.0	102.7	102.9
Total science[b]	0.4	0.5	0.5	0.8	1.6	2.4	2.7	3.0	4.3	5.8	10.1
Flight projects											
TOPEX/POSEIDON	1.2	2.1	2.4	3.2	4.7	9.0	68.8	76.9	96.5	78.7	62.7
(science funds)	0.4	0.5	0.5	0.6	0.6	0.6	0.8	1.0	1.8	2.0	5.3
NSCAT	—	—	—	10.3	11.7	26.2	18.3	8.0	11.4	20.6	28.3
(science funds)	—	—	—	0.1	0.5	1.2	1.2	1.2	1.2	1.3	1.6
ASF and NSIDC	—	—	—	0.5	1.0	5.0	7.4	3.1	2.9	3.2	4.5
(science funds)	—	—	—	0.1	0.5	0.6	0.7	0.8	1.3	2.5	3.2
SeaWiFS	—	—	—	—	—	—	0.1	0.2	4.5	6.0	17.5
(science funds)	—	—	—	—	—	—	0	0	0	0	0
Total federal ocean science[a]	364.0	369.9	343.5	350.3	345.0	363.6	373.8	412.9	424.6	493.9	518.0

NOTE: All 1992 values are estimates; NA = not available.

[a] Individual values are summed to obtain the total federal ocean science figure.

[b] Individual values are summed to obtain the NASA total ocean science figure.

TABLE 4-8 Ocean Science Federal Agency Budget History: Constant 1982 Dollars (millions)

Agency	Fiscal Years 1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
ONR total SE 31 and 32[a]	71.0	63.3	60.8	62.7	55.9	66.6	70.5	69.0	65.1	73.3	71.3
SE 31 ocean science	35.5	35.7	36.4	35.1	36.3	42.8	45.8	40.4	38.4	42.4	39.4
SE 32 ocean geophysics	27.5	27.0	25.6	23.4	25.4	24.6	25.9	27.9	26.7	25.3	27.5
SE 33-03 marine meteorology	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.4
Total NSF (overall)	995.6	1,050.4	1,221.3	1,341.9	1,269.2	1,364.9	1,385.8	1,485.1	1,536.4	1,651.1	1,730.3
NSF (total ocean science)[a]	95.0	98.5	105.5	108.3	103.9	112.4	109.0	112.7	108.9	114.9	120.2
OSRS	46.4	47.9	50.9	52.1	49.5	55.9	54.2	54.7	53.9	57.2	61.1
B.O.	10.7	11.3	11.9	12.4	11.6	12.1	11.9	13.2	12.8	14.2	15.5
C.O.	10.1	10.4	11.1	11.1	10.4	11.3	11.0	11.2	11.0	11.2	11.7
MG and G	12.0	12.1	13.5	13.6	12.7	13.6	13.1	12.4	11.8	12.1	12.9
P.O.	13.6	14.1	14.4	15.0	14.9	18.9	18.4	18.0	18.3	19.7	20.9
DSDP/ODP (total)	20.5	20.2	24.3	24.8	25.1	25.2	24.7	24.2	23.7	24.4	24.5
OCF	28.1	30.4	30.4	31.5	29.3	31.3	30.0	33.7	31.4	33.3	34.7
NOAA (total ocean science)[a]	117.9	128.4	84.5	74.8	75.3	63.5	59.2	62.4	60.4	59.0	56.2
Sea Grant	22.5	21.9	21.7	22.3	22.4	21.8	20.5	19.2	20.1	17.7	21.4
Global Change	—	—	—	—	—	—	—	4.2	7.0	14.8	14.3
Coastal Ocean Program	—	—	—	—	—	—	—	—	4.7	7.5	7.7
DOE (total ocean science)[a]	14.6	6.8	8.6	8.4	6.7	6.1	5.5	6.9	7.5	7.2	8.2
Oceans Research	9.9	4.8	6.1	6.0	4.4	4.5	4.1	4.5	4.3	3.1	3.7
Global Change	4.7	2.0	2.5	2.4	2.3	1.6	1.4	2.5	3.2	4.0	4.5

USGS[a]	21.9	12.5	17.2	19.2	22.0	21.9	23.0	22.8	23.9	26.3	24.7
MMS[a]	27.0	29.0	23.4	21.3	17.1	15.7	15.4	13.1	12.6	17.5	10.1
EPA[a]	NA	NA	NA	NA	NA	NA	NA	12.5	15.6	24.8	33.1
NASA (total ocean science)[ab]	16.6	16.8	17.3	18.3	19.3	19.5	19.1	19.5	19.7	21.7	24.5
(including satellites)	17.4	18.3	19.0	30.1	33.1	51.3	93.3	85.3	101.8	93.4	93.7
Research and analysis[b]	16.2	16.3	16.8	17.6	17.9	17.5	16.9	17.2	16.6	17.7	17.8
University science	3.3	3.8	3.5	4.8	3.5	4.6	5.7	6.2	8.5	8.6	8.5
Flight projects total	1.2	2.0	2.2	12.5	15.1	33.8	76.4	68.1	85.2	75.7	76.0
Total nonscience	0.8	1.5	1.7	11.8	13.7	31.8	74.2	65.8	82.0	71.7	69.2
Total science[b]	0.4	0.5	0.5	0.7	1.4	2.0	2.2	2.3	3.2	4.0	6.8
Flight projects											
TOPEX/POSEIDON	1.2	2.0	2.2	2.9	4.1	7.6	55.5	59.4	71.3	54.9	42.2
(science funds)	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.8	1.3	1.4	3.6
NSCAT	—	—	—	9.2	10.2	22.0	14.8	6.2	8.4	14.4	19.0
(science funds)	—	—	—	0.1	0.4	1.0	1.0	0.9	0.9	0.9	1.1
ASF and NSIDC	—	—	—	0.4	0.9	4.2	6.0	2.4	2.1	2.2	3.0
(science funds)	—	—	—	0.1	0.4	0.5	0.6	0.6	1.0	1.7	2.2
ScaWiFS	—	—	—	—	—	—	0.1	0.2	3.3	4.2	11.8
(science funds)	—	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0
Total federal ocean science[a]	364.0	355.3	317.3	313.0	300.2	305.7	301.7	318.9	313.7	344.7	348.3

NOTE: All 1992 values are estimates; NA = not available.

[a] Individual values are summed to obtain the total federal ocean science figure.
[b] Individual values are summed to obtain the NASA total ocean science figure.

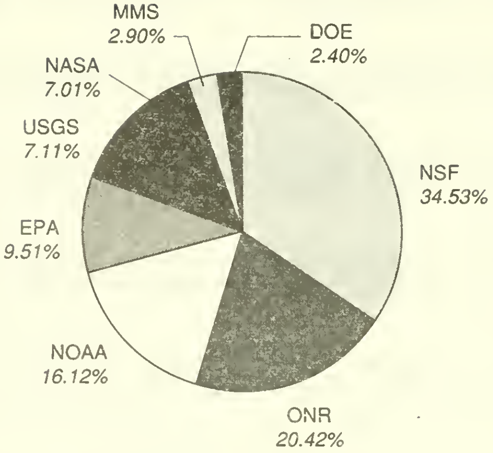


FIGURE 4-20 Distribution of federal support for ocean science in Fiscal Year 1992.

1982 dollars. The NSF budget grew at an annual rate of 14.4 percent during this time. More than half of this increase can be attributed to inflation; in constant 1982 dollars, the total NSF budget increased at an annual rate of 6.7 percent. This impressive record indicates continuing support in both the administration and the Congress for basic scientific research.

Ocean Science The budget of NSF's Ocean Sciences Division (OCE) has not increased as rapidly as the overall NSF budget over this same period (Figure 4-21). In constant 1982 dollar terms, the OCE budget grew 2.4 percent annually between fiscal years 1982 and 1992, a constant dollar growth rate about one-third that of the overall NSF budget. Of the OCE growth, in constant 1982 dollar terms, 58 percent can be attributed to growth specifically in Ocean Science Research Support (OSRS). The Ocean Drilling Program (ODP) accounts for 16 percent of the constant 1982 dollar growth and Oceanographic Centers and Facilities (OCF) for 26 percent. It is encouraging to note that the 5.5 percent increase in the OCE budget from fiscal years 1990 to 1991 (in constant 1982 dollars) and the 4.6 percent budget increase from 1991 to 1992 may signal significant real growth in the OCE budget in the 1990s.

Funding increases have not been uniform across the oceanographic disciplines in OCE (Figure 4-22). The physical oceanography budget increased more than the other three disciplines, ac-

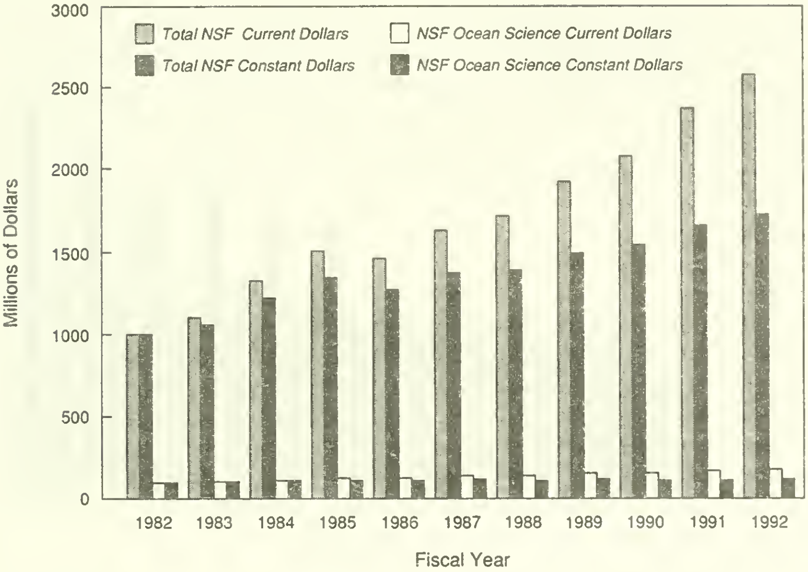
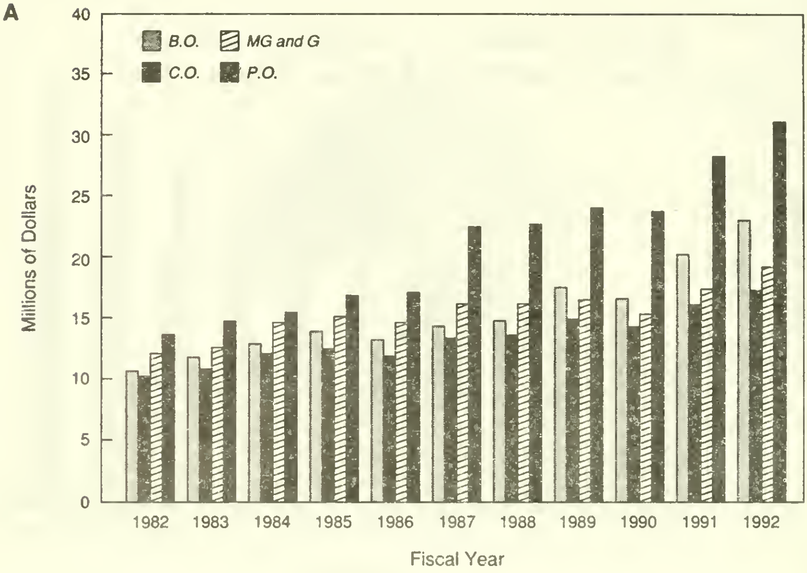


FIGURE 4-21 Budget history of the National Science Foundation and the ocean science component in current and constant 1982 dollars for Fiscal Years 1982–1992.

counting for 53 percent (in inflation-adjusted dollars) of the entire OSRS growth between fiscal years 1982 and 1992. Biological oceanography accounted for 33 percent of the OSRS growth. In contrast, increases in the chemical oceanography and marine geology and geophysics budgets accounted for much smaller percentages of the OSRS growth, 11 and 6 percent, respectively. However, this relatively slow growth in core program support for MG and G has been offset by a $5 million to $6 million budget per year for drilling-related science that began when ODP was established in the mid-1980s.

Thus at NSF, 1982–1992 was characterized by slow growth in research support for ocean sciences. Further, the percentage growth occurred mostly in OSRS and can be attributed primarily to increased support in physical oceanography and, in fiscal years 1991 and 1992, biological oceanography as well.

Other Basic Sciences Overall, NSF support for most fields of basic scientific research grew relatively slowly from fiscal years 1982 to 1992. The three directorates that fund most of NSF's



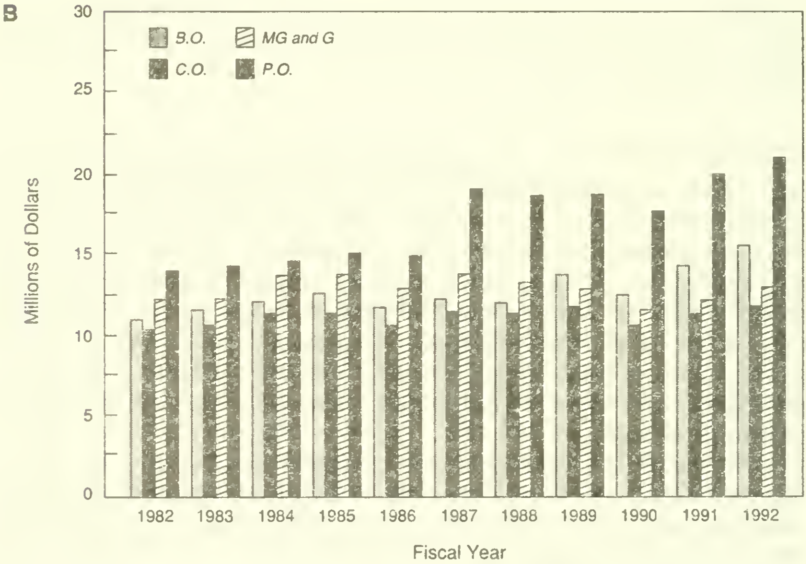


FIGURE 4-22 Budget history of the National Science Foundation's ocean science disciplines in current dollars (A) and in constant 1982 dollars (B) for Fiscal Years 1982–1992.

basic scientific research (and comprise more than one-half its total budget)—Biological, Behavioral and Social Sciences, Mathematics and Physical Sciences, and Geosciences—had budget growth rates substantially lower than the overall NSF budget. NSF directorates responsible for technology, computing, engineering, and education accounted for most of the percentage growth in the overall NSF budget.

Office of Naval Research

The Department of the Navy, primarily through the ONR, has been a major supporter of basic oceanographic research in the United States. ONR funding has changed little in constant dollars since fiscal year 1982 (Figure 4-23). Funding by ONR's oceanographic disciplines, which differ from NSF's, are also relatively constant (Figure 4-23).

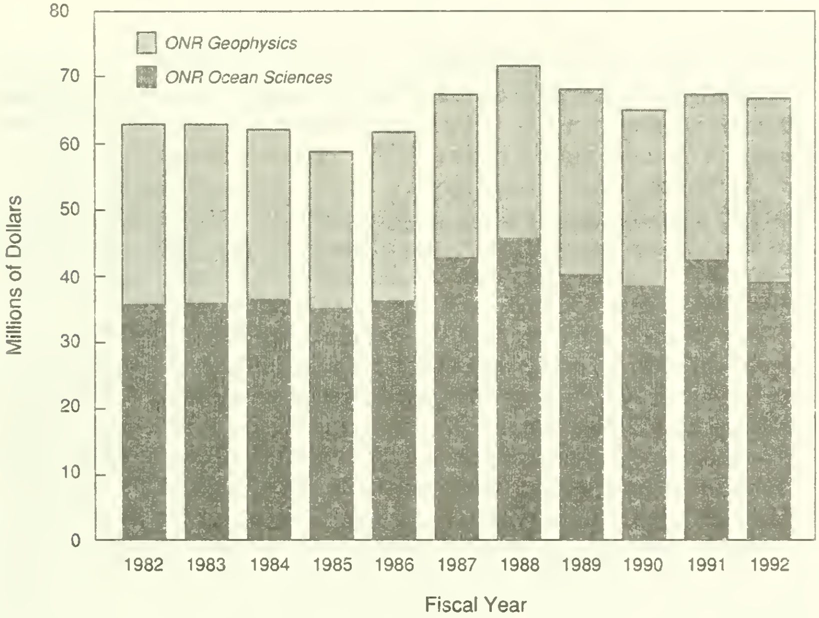


FIGURE 4-23 Office of Naval Research funding for ocean science in constant 1982 dollars for Fiscal Years 1982–1992.

Office of the Oceanographer of the Navy

The Office of the Oceanographer of the Navy was the program sponsor for the following new construction of Navy-owned ships assigned to academic institutions between fiscal years 1982 and 1992:

$33 million	AGOR-23 (R/V *Thompson)*	New construction
$47 million	R/V *Knorr*, R/V *Melville*	Refitting
$41 million	AGOR-24	New construction

Other Navy Support

Other Navy support for ocean science comes from the Office of Naval Technology (ONT) and the Naval Research Laboratory (NRL). ONT provided $43.7 million in fiscal year 1992 for science, but no breakdown for ocean science is available. Further, no budget figures are available prior to fiscal year 1992. NRL provided $3.2 million in fiscal year 1992 for ocean science; here too, no prior budget figures are available yet.

National Oceanic and Atmospheric Administration

NOAA's research budget includes mapping, charting, geodesy activities, ocean and coastal management, climate research, and fisheries management (Figure 4-24). NOAA research is carried out at major federal laboratories, such as the Atlantic Oceanographic and Meteorological Laboratories and the Pacific Marine Environmental Laboratories, as well as through cooperative agreements with universities and the National Sea Grant College, Climate and Global Change, and Coastal Ocean programs.

Sea Grant, NOAA's major extramural funding program for university-based scientists, provided approximately $25.3 million in fiscal year 1991 for ocean science research (Figure 4-25). The Climate and Global Change Program began in fiscal year 1989 and provides some support for academic scientists (Figure 4-25). The Coastal Ocean Program (COP) began in fiscal year 1990. Approximately 50 percent of its $11.5 million budget for fiscal year 1992 is used to support academic research in coastal ocean science (Figure 4-25). Although it is a young program, COP indicates a possible trend of increasing academic research support (164 percent between fiscal years 1990 and 1992 in constant 1982 dollars). If its budget continues to increase and congressional support continues, COP may emerge as a significant extramural funding pro-

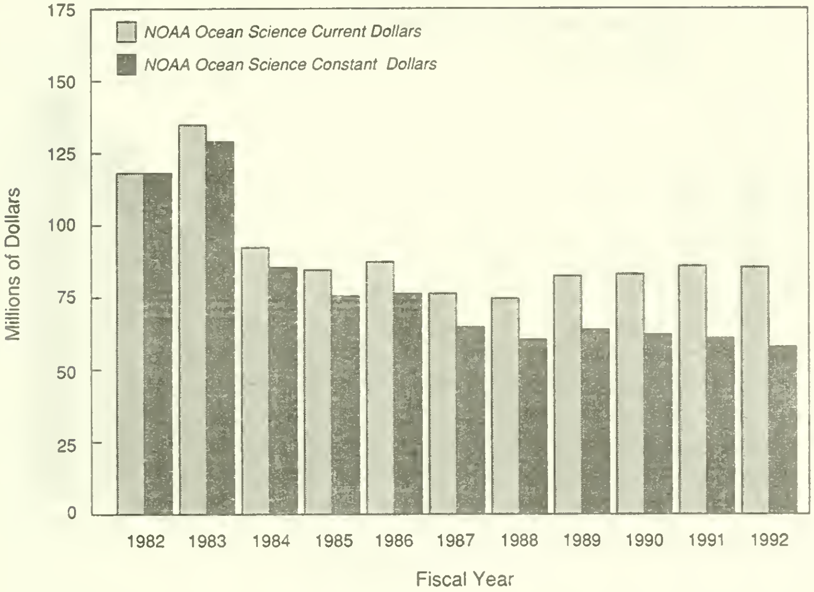


FIGURE 4-24 National Oceanic and Atmospheric Administration (NOAA) funding for ocean science in current and constant 1982 dollars for Fiscal Years 1982–1992.

gram in the 1990s. Funding information for these three NOAA programs is included in Tables 4-7 and 4-8.

Department of Energy

For many years, the Department of Energy has supported a marine research program in areas such as subseabed waste disposal, carbon dioxide-related research, and coastal oceanography (Figures 4-26 and 4-27). In fiscal year 1982, the marine research program was budgeted at $22.9 million, with some of the work contracted to university-based marine scientists. Between fiscal years 1982 and 1987, the budget was reduced nearly 75 percent in constant 1982 dollar terms. Programs in subseabed waste disposal and strategic petroleum were eliminated, and funding for coastal oceanography and carbon dioxide research was reduced. With DOE involvement in the U.S. Global Change Program, funding for carbon dioxide-related research has rebounded. Since fis-

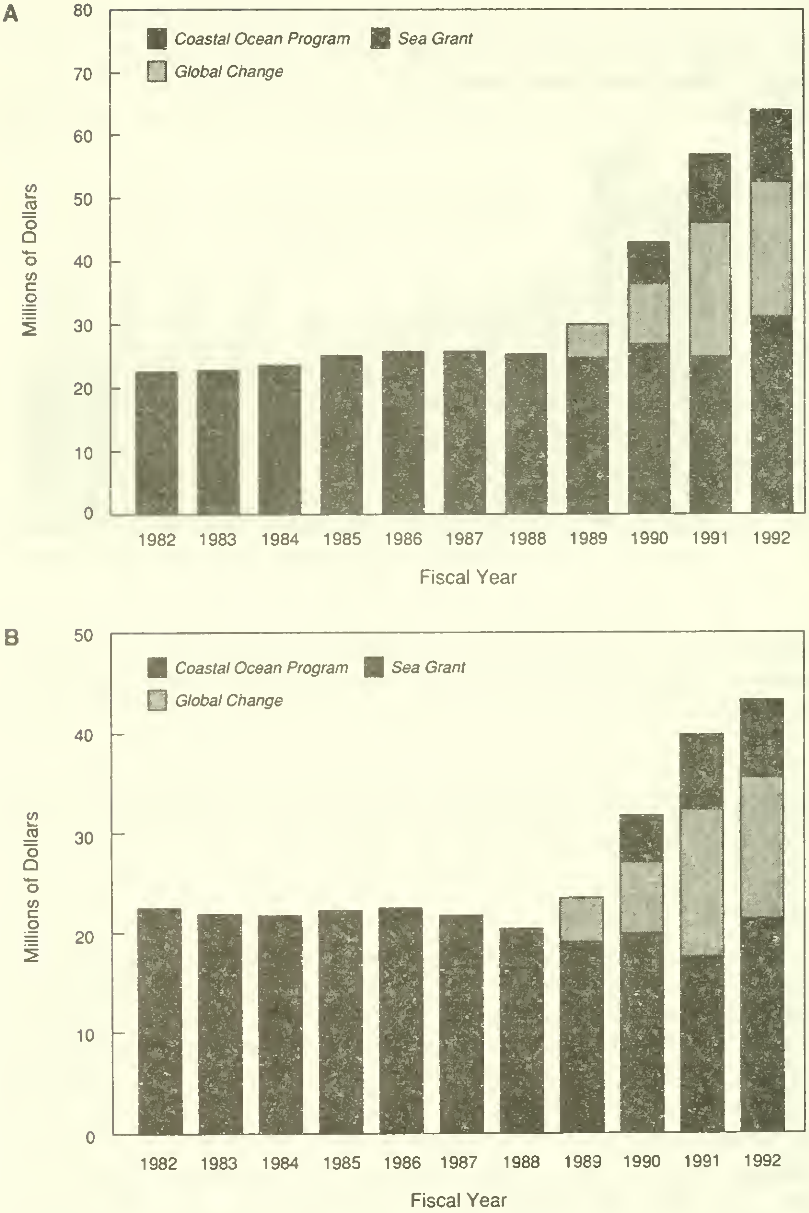


FIGURE 4-25 Budget history of the National Oceanic and Atmospheric Administration's Sea Grant, Coastal Ocean Program, and Global Change ocean science components in current dollars (A) and in constant 1982 dollars (B) for Fiscal Years 1982–1992.

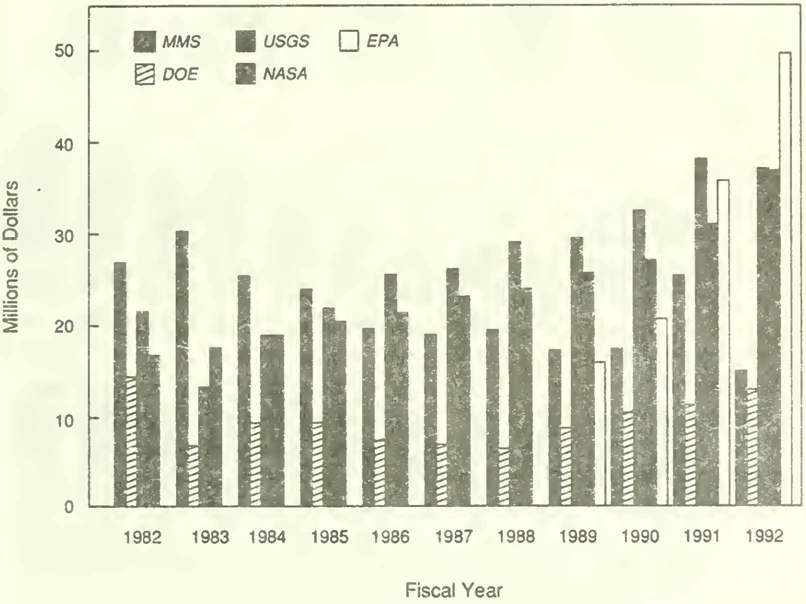


FIGURE 4-26 Budget history of ocean science research programs in several major federal mission agencies in current dollars for Fiscal Years 1982–1992.

cal year 1987, DOE funding for ocean-related research increased 6.6 percent annually in constant 1982 dollar terms, but it is still significantly (63 percent) below the level of fiscal year 1982 support in constant 1982 dollars.

U.S. Geological Survey

USGS supports marine geological and geophysical research. During the past decade, it has emphasized mapping and assessing the geological resources of the U.S. Exclusive Economic Zone. USGS ocean science funding—which includes two major components, Offshore Geologic Framework and Coastal Geology—decreased 32 percent in constant 1982 dollars from fiscal year 1982 to 1983 (Figures 4-26 and 4-27). This reduction is due in part to the formation of a new bureau MMS, which was separated from the Conservation Division unit in the Department of the Interior in fiscal year 1982. Since fiscal year 1983, the USGS marine programs budget has grown 65.8 percent in constant 1982 dollar terms, a 6.6 percent annual average increase.

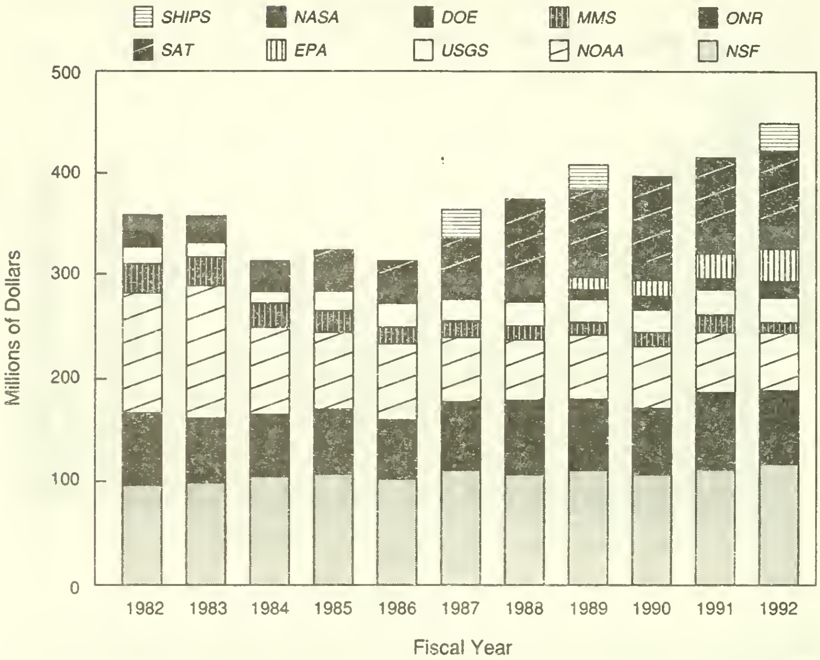


FIGURE 4-27 Total federal support for ocean science including NASA satellites and Navy ships assigned to academic institutions, in constant 1982 dollars for Fiscal Years 1982–1992.

Minerals Management Service

MMS's Environmental Studies Program supports studies in physical oceanography, offshore geology, and marine pollution. Some studies are contracted with university-based researchers, and others are conducted by private industry or federal agencies (e.g., USGS). In general, the MMS ocean science budget has decreased continuously from fiscal year 1982 to fiscal year 1992, for a 63 percent overall decrease in constant 1982 dollars in these 11 years (Figures 4-26 and 4-27).

Environmental Protection Agency

EPA has a rapidly growing marine research program. Reliable figures are not available prior to fiscal year 1989, but between fiscal years 1989 and 1992, the EPA marine program budget increased 165 percent in constant 1982 dollars (an average annual increase of 41 percent), the largest percent increase in any federal agency (Figures 4-26 and 4-27).

National Aeronautics and Space Administration

Satellites are increasingly important in modern oceanographic research. NASA provides funding for construction, operation, and related research for ocean satellite missions such as TOPEX/Poseidon, instruments such as SeaWiFS and the NASA Scatterometer, and data collection and analysis from other satellites such as ESA's Earth Resources Satellite-1 (see "Physical Resources"). It is difficult from NASA's budget presentation to identify specific ocean-related funding after fiscal year 1989, except for individual satellites. Expenditures for fiscal years 1982–1992 are shown in Tables 4-7 and 4-8 in two categories, Research and Analysis and Flight Programs. Funding of university-based researchers has nearly quadrupled in current dollars, from \$3.3 million in 1982 to \$12.6 million in 1992. NASA's ocean-related funding has grown, particularly for the development of new satellite sensors. Growth of NASA's budget in Earth observations is expected to be substantial as the Mission to Planet Earth begins and the Earth Observing System satellites are developed.

Discussion

Overall, federal funding of oceanographic research in the 1980s was relatively constant. Figure 4-27 shows that total federal spending on oceanographic research grew 5.1 percent from fiscal year 1982 to fiscal year 1992 (in constant 1982 dollars), an increase of about 0.6 percent annually.

Although this report focuses on funding trends in the ocean sciences, funds for individual oceanographic investigators are influenced by the rapid growth in the number of academic oceanographers and a significant increase in the costs of ocean science. Throughout the period of slow growth in federal spending on the ocean sciences in the 1980s, the number of scientists competing for funds continued to grow. According to the OSB survey (see "Human Resources"), the number of Ph.D.-level academic ocean scientists increased about 70 percent from 1980 to 1990. WHOI data indicate that the number of proposals per staff member increased from 2.8 in 1975 to 4.8 in 1991. This finding seems to confirm a general impression among research oceanographers that they now spend more time writing proposals than in the past.

The costs of the latest equipment (e.g., ships, satellites, and laboratory instrumentation) used in oceanography today are rising much faster than the rate of inflation. This trend, seen in many scientific fields, is what D. Allan Bromley, the President's Science Advisor, calls the sophistication factor. For example, all major oceanographic research vessels in the 1970s were equipped with wide-beam echo sounders to measure the water depth beneath the ship. These simple systems cost a few thousand dollars to install and were inexpensive to operate. In the 1980s, the first multiple narrow-beam echo sounders were introduced. These systems produced more accurate seafloor maps up to 16 times faster than the older echo sounders, but they cost nearly $1 million per ship to install and are much more costly to operate and maintain. In the early 1990s, the second-generation multibeam swath mapping systems were introduced. They are up to 10 times faster than the first multibeam systems but cost nearly 2.5 times as much. This example is not atypical; each oceanography discipline could cite similar examples. As our capability to do oceanographic research has increased over the past 20 years, the associated costs of acquiring, operating, and maintaining modern facilities and equipment have outpaced inflation.

References

Altabet, M.A. 1989. Particulate new nitrogen fluxes in the Sargasso Sea. Journal of Geophysical Research 94:12771-12779.

Battisti, D.S., and B.M. Hickey. 1984. Application of remote wind-forced coastal trapped wave theory to the Oregon and Washington coasts. Journal of Physical Oceanography 14:887-903.

Baumgartner, A., and E. Reichel. 1975. The World Water Balance. Amsterdam, Holland: Elsevier, 179 pp.

Berger, W.H. 1988. Global maps of ocean productivity. Pp. 429-455 in Productivity of the Ocean: Present and Past, W. H. Berger, V. S. Smetacek, and G. Wefer, eds. New York: John Wiley & Sons.

Boning, C.W., R. Doscher, and R.G. Budich. 1991. Seasonal transport variation in the western subtropical North Atlantic: Experiments with an eddy-resolving model. Journal of Physical Oceanography 21:1271-1289.

Boyle, E.A. 1990. Quaternary deepwater paleoceanography. Science 249: 863-870.

Brassell, S.C., G. Eglinton, I.T. Marlowe, U. Pflaumann, and M. Sarnthein. 1986. Molecular stratigraphy: A new tool for climatic assessment. Nature 320:129-133.

Bush, V. 1945. Science—The Endless Frontier. A report to the president on a program of postwar scientific research. Washington, D.C.: U.S. Government Printing Office, 184 pp.

Chamberlin, W.S., C.R. Booth, D.A. Kiefer, J.H. Morrow, and R.C. Murphy. 1990. Deep-Sea Research 37:951-973.

Cushing, D.H. 1982. Climate and Fisheries. New York, N.Y.: Academic Press, 373 pp.

Detrick, R.S., P. Buhl, E. Vera, J. Mutter, J. Orcutt, J. Madsen, and T. Brocher. 1987. Multichannel seismic imaging of a crustal magma chamber along the East Pacific Rise. Nature 326:35-41.

Dickson, R.R., J. Meincke, S.-A. Malmberg, and A. Jake. 1988. The great salinity anomaly. Progress in Oceanography 20:103-151.

Environmental Protection Agency Science Advisory Board. 1990. Reducing Risk. Washington, D.C.: U.S. Government Printing Office, 33 pp. (appendixes, 361 pp).

Federal Coordinating Council for Science, Engineering, and Technology. 1992. Grand Challenges: High Performance Computing and Communications. The FY 1993 U.S. Research and Development Program. A Report by the Committee on Physical, Mathematical, and Engineering Sciences. Washington, D.C.: U.S. Government Printing Office.

Geernaert, G. 1990. Bulk parameterizations for the wind stress and heat fluxes. Pp. 91-172 in Surface Waves and Fluxes: Theory, Vol. 1, G. Geernaert and W. Plant, eds. Netherlands: Kluwer Academic Publishers.

Gordon, A.L., R.F. Weiss, W.M. Smethie, Jr., and M.J. Warner. 1992. Thermocline and intermediate water communication between the South Atlantic and Indian Oceans. Journal of Geophysical Research 97:7223-7240.

Joint Oceanographic Institutions Satellite Committee. 1985. Oceanography from Space. A Research Strategy for the Decade 1985-1995. Part 1, Executive Summary; Part 2, Proposed Measurements and Missions. Washington, D.C.: JOI, Inc.

Kennett, J.P. 1977. Cenozoic evolution of Antarctic glaciation, the circumantarctic ocean and their impact on global paleoceanography. Journal of Geophysical Research 82:3843-3860.

Kullenberg, G. 1986. Long-term changes in the Baltic ecosystem. Pp. 19-32 in Variability and Management of Large Marine Ecosystems, K. Sherman and L.M. Alexander, eds. Washington, D.C.: American Association for the Advancement of Science Selected Symposium 99.

Lampitt, R.S. 1990. Directly measured rapid growth of a deep-sea barnacle. Nature 345:805-807.

Larson, R.L. 1991. Geological consequences of superplumes. Geology 19:963-966.

Lee, T. N., J. A. Yoder, and L. P. Atkinson. 1991. Gulf Stream frontal eddy influence on productivity of the southeast U.S. continental shelf. Journal of Geophysical Research 96:191-205.

Manabe, S., and R.J. Stouffer. 1988. Two stable equilibria of a coupled ocean-atmosphere model. Journal of Climate 1:841-866.

Mantoura, R.F.C., Martin, J.M., and R. Wollast, eds. 1991. Ocean margin processes in global change. Dahlem Workshop Reports; Physical, Chemical, and Earth Sciences Research Report 9. March 18-23, 1990, Berlin.

McGowan, J.A. 1990. Climate and change in oceanic ecosystems: The value of time-series data. Trends in Ecology and Evolution 5:293-299.

Moore III, B., and B. Bolin. 1986. The oceans, carbon dioxide and global climate change. Oceanus 29:9-15.

National Research Council. 1970. Growth and Support of Oceanography in the United States. Washington, D.C.: National Academy Press, 44 pp.

National Research Council. 1971. Ocean Science Manpower Data and Their Interpretation. Washington, D.C.: National Academy Press, 19 pp.

National Research Council. 1972. Ocean Science Graduate Students. Washington, D.C.: National Academy Press, 18 pp.

National Research Council. 1981. Doctoral Scientists in Oceanography. Washington, D.C.: National Academy Press, 155 pp.

National Science Foundation. 1975. Characteristics of Doctoral Scientists and Engineers in the United States: 1973. NSF 75-312. Washington, D.C.

National Science Foundation. 1977. Characteristics of Doctoral Scientists and Engineers in the United States: 1975. NSF 77-309. Washington, D.C.

National Science Foundation. 1979. Characteristics of Doctoral Scientists and Engineers in the United States: 1977. NSF 79-306. Washington, D.C.

National Science Foundation. 1981. Characteristics of Doctoral Scientists and Engineers in the United States: 1979. NSF 80-323. Washington, D.C.

National Science Foundation. 1983. Characteristics of Doctoral Scientists and Engineers in the United States: 1981. NSF 82-332. Washington, D.C.

National Science Foundation. 1985. Characteristics of Doctoral Scientists and Engineers in the United States: 1983. NSF 85-303. Washington, D.C.

National Science Foundation. 1987. Characteristics of Doctoral Scientists and Engineers in the United States: 1985. NSF SRS-86-D3. Washington, D.C.

National Science Foundation. 1989. Characteristics of Doctoral Scientists and Engineers in the United States: 1987. NSF 88-331. Washington, D.C.

National Science Foundation. 1991. Characteristics of Doctoral Scientists and Engineers in the United States: 1989. NSF 91-317. Washington, D.C.

Nichols, F.H. 1985. Abundance fluctuations among benthic invertebrates in two Pacific estuaries. Estuaries 8:136-144.

O'Brien, J.J., ed. 1985. Advanced Physical Oceanographic Numerical Modelling. Boston: Dordrecht, 608 pp.

Office of Management and Budget. 1992. Budget of the United States Government. Fiscal Year 1993. Washington, D.C.: U.S. Government Printing Office.

Prahl, F.G., and S.G. Wakeham. 1987. Calibration of unsaturation patterns in long-chain ketone compositions for paleotemperature assessment. Nature 330:367-369.

Rona, P.A., G. Klinkhammer, T.A. Nelson, J.H. Trefry, and H. Elderfield. 1986. Black smokers, massive sulphides, and vent bacteria at the Mid-Atlantic Ridge. Nature 321:33-37.

Rothschild, B. J., and P. R. Osborn. 1988. Small-scale turbulence and plankton contact rates. Journal of Plankton Research 10(3):465-474.

Semtner, A.J., and R.M. Chervin. 1992. Ocean general circulation from a global eddy-resolving model. Journal of Geophysical Research 97: in press.

Shackleton, N.J. 1987. Oxygen isotopes, ice volumes, and sea level. Quaternary Science Reviews 6:183-190.

Sissenwine, M.P. 1986. Perturbation of a predator-controlled continental shelf ecosystem. Pp. 55-86 in Variability and Management of Large Marine Ecosystems, K. Sherman and L.M. Alexander, eds. Washington D.C.: American Association for the Advancement of Science Selected Symposium 99.

Stewart, R. H. 1985. Methods of Satellite Oceanography. Berkeley: University of California Press, 360 pp.

Stommel, H. 1961. Thermohaline convection with two stable regimes of flow. Tellus 13(2):224-230.

Tans, P.P., I.Y. Fung, and T. Takahashi. 1990. Observational constraints on the global atmospheric CO_2 budget. Science 247:1431-1438.

University-National Oceanographic Laboratory Systems. 1991. Summary Report of the UNOLS Annual Meeting. October 17, 1991, Washington, D.C.

Walsh, J.J. 1991. Importance of continental margins in the marine biogeochemical cycling of carbon and nitrogen. Nature 350:53-55.

Watson, A.J., and J.R. Ledwell, 1988. Purposefully released tracers. Philos. Trans. R. Soc. London Ser. A 325:189-200.

Weyl, P.K. 1968. The role of the oceans in climate change: A theory of the ice ages. Meteorological Monographs 8:37-62.

World Ocean Circulation Experiment Scientific Steering Group. 1986. Scientific Plan for the World Ocean Circulation Experiment. World Climate Research Programme, WCRP Publications Series, No. 6, Geneva, Switzerland: World Meteorological Organization WMO/TD- No. 122, 83 pp.

Yoder, J.A., L.P. Atkinson, T.N. Lee, H.H. Kim, and C.R. McClain. 1981. Role of Gulf Stream frontal eddies in forming phytoplankton patches on the outer southeastern shelf. Limnology and Oceanography 26:1103-1110.

Zoback, M.D., D. Moss, L. Mastin, and R.N. Anderson. 1985. Well-bore breakouts and in situ stress. Journal of Geophysical Research 90:5523-5530.

APPENDIXES

I

How the Study Was Conducted

This study is the result of several years' activity by the Ocean Studies Board (OSB) and the U.S. ocean science community. The Board convened three workshops, one on facilities (May 30-31, 1990) and two on future science directions in oceanography (March 11-12 in Irvine, California and April 22, 1991 in Washington, D.C.). Additional community input was sought through two special sessions at meetings of the American Geophysical Union. In addition, the OSB surveyed federal agencies and academic institutions on fiscal, physical, and human resources.

The OSB especially thanks scientists who were not members of the Board during the duration of this study but who contributed to or reviewed portions of this report or contributed at one of its workshops:

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II

Abbreviations and Acronyms

ACOS	Advisory Committee on Ocean Sciences (ACOS)
ALT	Radar altimeter
ARISTOTELES	Applications and Research Involving Space Technologies Observing the Earth's Field from Low Earth Orbiting Satellites
ARM	Atmospheric Radiation Measurements program (DOE)
BLM	Bureau of Land Management
B.O.	Biological oceanography
CHAMMP	Computer Hardware, Advanced Modeling and Model Physics program
CNES	French space agency
C.O.	Chemical oceanography
COA	Council on Ocean Affairs
COP	Coastal Ocean Program (NOAA)
CS	Color scanner
DIN	dissolved inorganic nitrogen
DOC	dissolved organic carbon
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior

DOM	dissolved organic material
DON	dissolved organic nitrogen
DSDP	Deep Sea Drilling Project
EEZ	Exclusive Economic Zone
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
EPA	Environmental Protection Agency
ERS-1	Earth Resources Satellite-1 (European Space Agency)
ESA	European Space Agency
FCCSET	Federal Coordinating Council for Science, Engineering, and Technology
FLIP	Floating Instrument Platform
FY	Fiscal Year
GLOBEC	Global Ocean Ecosystems Dynamics
GNP	gross national product
GOOS	global ocean observing system
IR	Infrared radiometer
JGOFS	Joint Global Ocean Flux Study
JOI	Joint Oceanographic Institutions, Inc.
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
M.B.	Marine biology
M.C.	Marine chemistry
MG and G	Marine geology and geophysics
MIT	Massachusetts Institute of Technology
MMS	Minerals Management Service (DOI)
MR	Microwave radiometer
NADW	North Atlantic Deep Water
NASA	National Aeronautics and Space Administration
NASDA	Japanese space agency
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
OCE	Division of Ocean Sciences (NSF)
OCF	Oceanographic Centers and Facilities (NSF)
OCS	outer continental shelf
ODP	Ocean Drilling Program
O.E.	Ocean engineering

ONR	Office of Naval Research
ONT	Office of Naval Technology
OSB	Ocean Studies Board
OSC	Orbital Sciences Corporation
OSRS	Ocean Science Research Support (NSF)
PI	principal investigator
P.O.	Physical oceanography
POM	particulate organic material
RIDGE	Ridge Inter-Disciplinary Global Experiment
ROV	remotely operated vehicle
R/V	research vessel
SAR	synthetic aperture radar
SCAT	Scatterometer
SeaWiFS	Sea-viewing Wide Field Sensor; an ocean color satellite instrument
SIO	Scripps Institution of Oceanography
TOGA	Tropical Ocean-Global Atmosphere program
TOPEX/Poseidon	Joint NASA/French Space Agency venture to measure the surface topography of the ocean with great precision
UH	University of Hawaii
UNOLS	University-National Oceanographic Laboratory System
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey (DOI)
UW	University of Washington
VOS	volunteer observing ships
WHOI	Woods Hole Oceanographic Institution
WOCE	World Ocean Circulation Experiment

III

Recent Workshop and Other Reports Relevant to Discussion in "Directions in Biological Oceanography"

Atlantic Climate Change Program Science Plan. 1990. NOAA Climate and Global Change Program Special Report No. 2. University Corporation for Atmospheric Research, Boulder, Colorado, 29 pp.

Atmosphere-Ocean Exchange of Carbon Dioxide: Implications for Climate and Global Change on Seasonal-to-Century Time-Scales. 1990. NOAA Climate and Global Change Program Special Report No. 3. University Corporation for Atmospheric Research, Boulder, Colorado, 31 pp.

Brink, K.H. and others. 1990. Coastal Ocean Processes (CoOP): Results of an Interdisciplinary Workshop. Contribution No. 7584, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, 51 pp.

Coastal Ocean Margin Flux Study (COMFS). 1988. A new DOE research initiative. Marine Research Program, Office of Energy Research, Department of Energy, Washington, D.C., 25 pp.

Deep Sea Observatories. 1989. Report of a conference to assess near-term opportunities and long-range goals of deep-sea observatories (DSOs). Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, 54 pp.

Dynamics of the continental margins: A report to the U.S. Department of Energy. 1990. Report NTIS-PR-360, National Technical Information Service, Springfield, Virginia, 55 pp.

Eden, H.F., and C.N.K. Mooers. 1990. Coastal Ocean Prediction Systems. Synopsis. JOI, Inc., Washington, D.C., 20 pp.

Global Ocean Ecosystems Dynamics. 1988. Report of a workshop on global ocean ecosystems dynamics. JOI, Inc., Washington, D.C., 131 pp.

Global Ocean Ecosystems Dynamics. 1991. GLOBEC Workshop on Biotechnology Applications to Field Studies of Zooplankton. Report Number 3. JOI, Inc., Washington, D.C.

Global Ocean Ecosystems Dynamics, 1991. Initial Science Plan. Report Number 1. JOI, Inc., Washington, D.C., 93 pp.

Global Ocean Ecosystems Dynamics. 1991. Theory and Modeling in GLOBEC: A first step. JOI, Inc., Washington, D.C.

Global Ocean Observing Systems Workshop Report. In press. JOI, Inc., Washington, D.C.

International Geosphere-Biosphere Programme (IGBP). 1990. Coastal Ocean Fluxes and Resources. IGBP Report Number 14. 53 pp.

Joint Global Ocean Flux Study. 1989. Report of the JGOFS Pacific Planning

Workshop, Honolulu. JGOFS Report Number 3. Scientific Committee on Oceanic Research-International Council of Scientific Unions. 68 pp.

Joint Global Ocean Flux Study Science Plan. 1990. JGOFS Report No. 5. Scientific Committee on Oceanic Research-International Council of Scientific Unions.

Joint Oceanographic Institutions, Inc. 1990. Initiatives for the accelerated transfer of biotechnology to the ocean sciences. Report of a workshop held September 16-18, 1988. Tucson, Arizona, 40 pp.

Recruitment Processes and Ecosystem Structure of the Sea. 1987. A report of a workshop. National Academy Press. Washington, D.C., 42 pp.

Sarachik, E.S., and R.H. Gammon. 1989. The role of the ocean in the NOAA program "Climate and Global Change." NOAA Climate and Global Change Program Special Report No. 1. University Corporation for Atmospheric Research, Boulder, Colorado, 49 pp.

U.S. Joint Global Ocean Flux Study Long Range Plan. 1990. U.S. JGOFS Planning Report Number 11. U.S. JGOFS Planning Office, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, 71 pp. plus appendixes.

IV

Oceanography Manpower Assessment Questionnaire (Academic Form)

1. Indicate the number of Ph.D. level staff (including post-docs) in your laboratory or department by sub-discipline from 1970-90.

	1970	1975	1980	1985	1990
B.O./M.B.	____	____	____	____	____
C.O./M.C.	____	____	____	____	____
MG&G	____	____	____	____	____
P.O.	____	____	____	____	____
O.E.	____	____	____	____	____

B.O./M.B. = Biological Oceanography/Marine Biology
C.O./M.C. = Chemical Oceanography/Marine Chemistry
MG&G = Marine Geology and Geophysics
P.O. = Physical Oceanography
O.E. = Ocean Engineering

2. Indicate the number of Ph.D. level staff by rank (Post-Doc, Assistant, Associate or Full Professors or equivalent research appointment) from 1970-90.

	1970	1975	1980	1985	1990
Post-Doc	____	____	____	____	____
Assist. Prof.	____	____	____	____	____
Assoc. Prof.	____	____	____	____	____
Full Prof.	____	____	____	____	____

3. Indicate the present age distribution of your Ph.D. level staff (i.e., faculty and staff with Principal Investigator status)

	Number of Ph.D.s				
	B.O./M.B.	C.O./M.C.	MG&G	P.O.	O.E.
<30	____	____	____	____	____
30-40	____	____	____	____	____
40-50	____	____	____	____	____
50-60	____	____	____	____	____
>60	____	____	____	____	____

4. Indicate the average number of months/years of institutional salary support ("hard money") provided to your Ph.D. level staff, including research series for each rank or its equivalent for 1990 for the most recent year available. Please exclude administrative support.

	Months/year
Post-doctoral Fellow	______________
Assistant Professor	______________

Associate Professor ________________

Full Professor ________________

5. Estimate (if possible) the number of Ph.D. level positions (replacement and new) that you anticipate filing in the next five years. What percentage of these will be institutionally supported (in average months per year)?

	B.O./M.B.	C.O./M.C.	MG&G	P.O.	O.E.
Replacement	_____	_____	____	____	____
New	_____	_____	____	____	____
% Supported	_____	_____	____	____	____

6. Institution name (will be kept confidential)

____

V

Oceanography Manpower Assessment Questionnaire (Federal Laboratory Form)

1. Indicate the number of Ph.D. level staff (including post-docs) in your laboratory or department by sub-discipline from 1970-90.

	1970	1975	1980	1985	1990
B.O./M.B.	____	____	____	____	____
C.O./M.C.	____	____	____	____	____
MG&G	____	____	____	____	____
P.O.	____	____	____	____	____
O.E.	____	____	____	____	____

B.O./M.B. = Biological Oceanography/Marine Biology
C.O./M.C. = Chemical Oceanography/Marine Chemistry
MG&G = Marine Geology and Geophysics
P.O. = Physical Oceanography
O.E. = Ocean Engineering

2. Indicate the present age distribution of your Ph.D. level staff (i.e., faculty and staff with Principal Investigator status).

Number of Ph.D.s

	B.O./M.B.	C.O./M.C.	MG&G	P.O.	O.E.
<30	____	____	____	____	____
30-40	____	____	____	____	____
40-50	____	____	____	____	____
50-60	____	____	____	____	____
>60	____	____	____	____	____

3. Estimate (if possible) the number of Ph.D. level positions (replacement) and new that you anticipate filling in the next five years.

	B.O./M.B.	C.O./M.C.	MG&G	P.O.	O.E.
Replacement	____	____	____	____	____
New	____	____	____	____	____

4. Laboratory name (will be kept confidential)

____

Principal source of funding ______________________________

VI

Institutional Respondents to Manpower Survey

Benedict Estuarine Research Laboratory
Columbia University, Lamont-Doherty Geological Observatory
Dauphin Island Sea Lab, Marine Environmental Sciences
Duke University Marine Laboratory
Florida State University, Department of Oceanography
Harbor Branch Oceanographic Institute, Inc.
Louisiana Universities Marine Consortium (LUMCON)
Monterey Bay Aquarium Research Institute
Moss Landing Marine Laboratories
Mote Marine Laboratory
New Jersey Marine Sciences Consortium
North Carolina State University, Department of Marine, Earth and Atmospheric Science
Nova University Oceanographic Center
Old Dominion University, Department of Oceanography
Oregon State University, College of Oceanography
Roger Williams College, School of Science and Mathematics
Skidaway Institute of Oceanography
State University of New York-Stony Brook, Marine Sciences Research Center
Texas A&M University, College of Geosciences, Department of Oceanography
University of Alaska, Institute of Marine Science

University of California-San Diego, Scripps Institution of Oceanography
University of California-Santa Barbara, Geology Department
University of California-Santa Barbara, Marine Science Institute
University of Delaware, College of Marine Studies
University of Georgia, UGA-Marine Institute
University of Hawaii, Hawaii Institute of Geophysics
University of Maine, Center for Marine Studies
University of Maryland, Center for Environmental and Estuarine Studies
University of Miami, Rosenstiel School for Marine and Atmospheric Sciences
University of Michigan, Center for Great Lakes and Aquatic Sciences
University of New Hampshire
University of Puerto Rico, Department of Marine Sciences
University of Rhode Island, Graduate School of Oceanography
University of Southern Mississippi, Center for Marine Science
University of South Florida, Department of Marine Science
University of Texas at Austin, Institute for Geophysics
University of the Virgin Islands
University of Washington, College of Ocean and Fishery Sciences
Virginia Institute of Marine Science, School of Marine Science
Woods Hole Oceanographic Institution

VII

Federal Respondents to Manpower Survey

Department of the Army
- U.S. Army Corps of Engineers

Department of Commerce, National Oceanic and Atmospheric Administration
- Environmental Research Laboratories (Office of Ocean and Atmospheric Research)
- Geodetic Research Laboratory (National Ocean Service)
- National Marine Fisheries Service laboratories
- Marine Mammal Laboratory (separate data as opposed to first three)

Department of Energy
- Argonne National Laboratory
- Brookhaven National Laboratory
- Oak Ridge National Laboratory
- Pacific Northwest Laboratory [Battelle Marine Sciences Laboratory]
- Savannah River Laboratory

Department of the Interior
- U.S. Geological Survey

Department of the Navy
- Naval Research Laboratory (Code 1005)
- Office of Naval Research (Codes 11 and 12)

Department of Transportation
- Coast Guard Academy
- U.S. Coast Guard Research and Development Center (Groton)

(•) International Ice Patrol (3 Ph.D. principal investigations since 1983), Oceanographic Unit (closed 1982)

National Aeronautics and Space Administration
- Goddard Oceans and Ice Branch
- Headquarters

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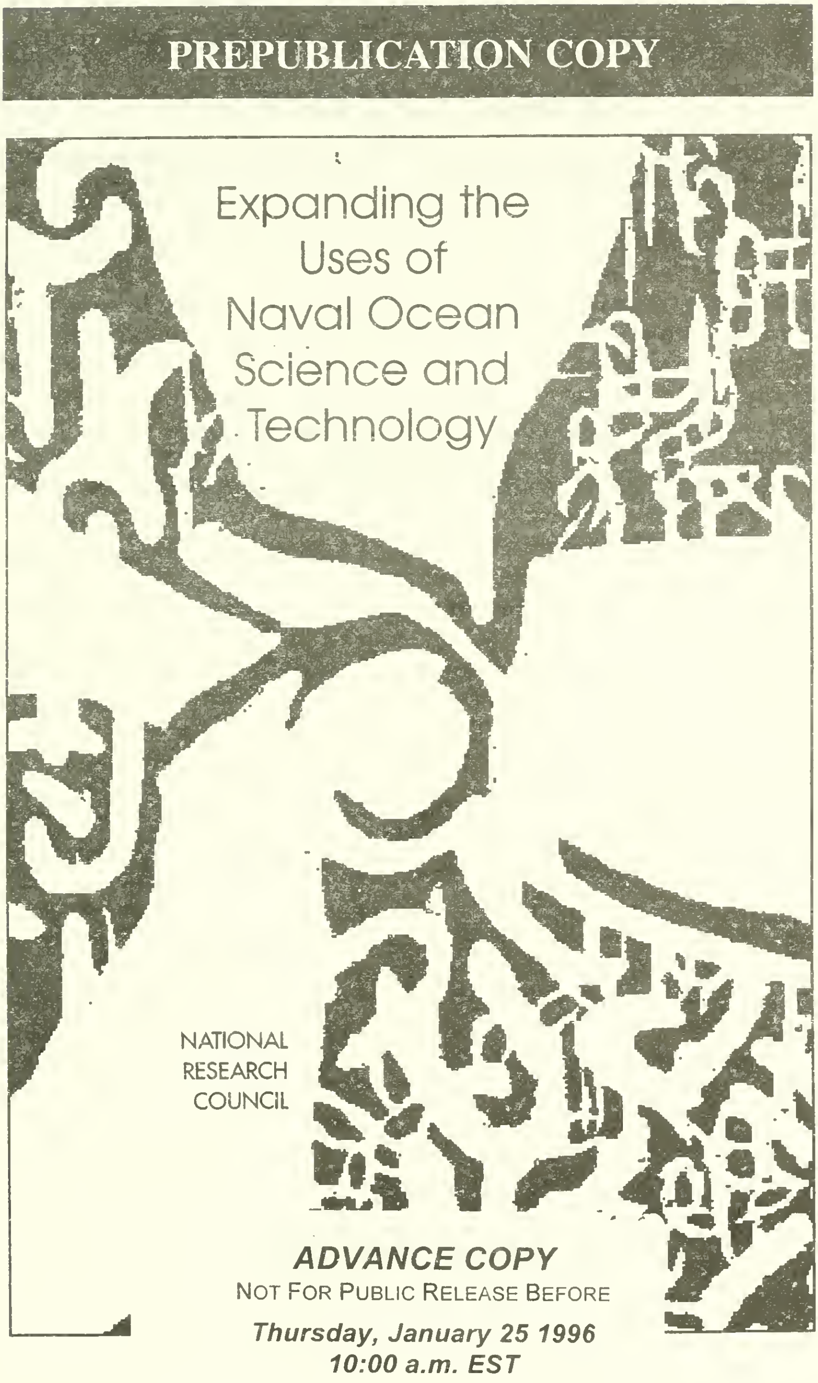

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Committee on Alternative Uses of Naval Technology
Ocean Studies Board
Commission on Geosciences, Environment, and Resources

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

As the United States adjusts to the end of the Cold War, global competitiveness is joining military preparedness as a national goal. The federal government is striving to achieve the proper balance between defense and domestic spending; consequently, greater emphasis is being placed on maximizing return on federal investment in research and development. Any activity that leads to more productive use of U.S. research dollars leads to a healthier economy and strengthens the national defense. The Department of the Navy is therefore exploring the nonmilitary benefits of naval technology. As discussed in a report of the National Research Council's Ocean Studies Board (OSB) *Oceanography in the Next Decade: Building New Partnerships*:

> Economic prosperity in a global marketplace depends increasingly on technical and scientific applications. There is concern about the ability of the United States to compete with Europe and Asia. Basic and applied research in the marine sciences and engineering is necessary to achieve and maintain a competitive position in a host of fields, including marine biotechnology, aquaculture, hydrocarbon and mineral exploration and production, maritime transportation, fisheries, treatment and disposal of waste, and freshwater extraction. (National Research Council, 1992a, p. 3-4)

Effective military use of the considerable scientific and engineering resources represented by the Office of Naval Research (ONR), Department of the Navy, relies on adequate and timely transfer of research and technology to the fleet. To maximize the nonmilitary benefits of naval research, similar accomplishments must be achieved in domestic technology transfer.

To help ONR improve its technology transfer efforts, James DeCorpo, Director of the Ocean, Atmosphere, and Space Department of ONR, requested that the OSB review the status of technology research in ONR laboratories and recommend programs that would serve to meet science and technology needs of the Navy, other agencies, industry, and academia. The OSB formed the Committee on Alternative Uses of Naval Technology in response to this request. The committee was further requested to produce a report detailing (1) how ONR now interacts with industry, (2) how those avenues of interaction may be improved, and (3) future areas of technology research that may be appropriate for ONR to pursue, which might have applications to interests outside the Navy. The committee did not discuss specific areas of basic research for ONR to pursue in the future (the OSB has provided such advice in more than 12 recent reports to ONR), but rather focused on establishing future technology needs of the nonmilitary industrial marine sector. This report, *Expanding the Uses of Naval Ocean Science and Technology*, offers advice that should lead to a more effective transfer of technology from ONR-sponsored scientists and laboratories to the nonmilitary marine sector. More effective use of U.S. defense research dollars could serve to strengthen scientific research, marine transportation, economic development, and global competitiveness.

WILLIAM MERRELL
Ocean Studies Board, *Chairman*

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Executive Summary

Following the end of the Cold War, the U.S. Department of Defense (DOD) began exploring use of defense technology by interests outside the military. The Office of Naval Research (ONR), including the Naval Research Laboratory and ONR-supported scientists and engineers at various research centers (e.g., the Naval Surface Warfare Center; the Naval Field Engineering System Center, formerly known as the Naval Civil Engineering Laboratory) and in academia, is a leader in oceanographic research and development of marine technologies. Technologies developed by ONR or through ONR funding may be useful to other government agencies (federal, state, and local), private industries, and academic scientists. The effective transfer of technology from DOD and its contractors to the civilian sector (e.g., academia, industry) is important for maintaining a strong national defense. Establishing closer links between ONR research and development (R&D) activities and nonmilitary users of marine technology may improve the effectiveness of U.S. research dollars and stimulate economic growth.

The Ocean Studies Board of the National Research Council was asked to review ONR programs, identify the needs of academia and the nonmilitary marine industry, and suggest ways to facilitate the transfer of naval research and technology to nonmilitary users. ONR and ONR-sponsored scientists and engineers conduct research and develop technology in a wide area (e.g., aeronautics, space science, ballistics) with potential interest to an equally broad range of nonmilitary industries and researchers. To provide a review that was both timely and comprehensive, the committee focused its attention on ONR-supported activities in ocean science and technology development. The committee studied the potential uses of ONR-supported marine technology outside the Navy by examining existing ONR programs and reviewing the needs of academic marine scientists, marine industries, and government agencies. The committee could not explore all possible industrial applications of ONR technology but instead focused its attention on four important marine user groups: (1) the oil and gas industry (i.e., exploration, production, and pipeline operation), (2) fisheries, (3) environmental companies, and (4) marine equipment and service providers. Because of their economic dominance, these four groups represent that segment of the nonmilitary, marine industrial sector that the committee concluded could benefit the most from future ONR-supported research and technology development. Examples of successful technology transfer strategies and programs employed by the National Aeronautics and Space Administration were also examined.

Information provided by representatives of ONR and the nonmilitary sector at committee meetings, as well as the resulting discussions, demonstrated that only a relatively small portion of the available marine technology developed by ONR is being used by the nonmilitary sector. The degree of transfer and causes of any suboptimal transfer differ for various user groups (e.g., academic scientists versus small commercial service providers). Despite this complexity, two themes emerged from the information gathered: (1) ONR appears to lack a suitable system to measure and reward successful transfer of technology to the nonmilitary sector, and (2) ONR does not appear to be sufficiently aware of private sector needs to target its technology transfer efforts effectively. The committee developed specific findings and recommendations related to ONR R&D and associated technology transfer programs.

ONR RESEARCH AND TECHNOLOGY DEVELOPMENT

Finding: The Office of Naval Research supports leading-edge research and development (R&D) in many areas of ocean science and technology with applications for nonmilitary users.

ONR-supported research accounts for a tremendous array of leading-edge scientific discoveries and technological developments with potential application to nonmilitary problems (see Chapter 4). These products range from coatings and materials to reduce ship corrosion at sea to sophisticated computer models for predicting the fate and transport of oil spills (see Chapter 2). The high-quality scientific research and technology development supported by ONR are an important component of the Navy's efforts to maintain combat readiness and tactical advantage. The committee recognizes that R&D supported by ONR is of vital importance to fleet effectiveness and national defense. Many of ONR's marine research programs and the resulting products, as well as the expertise they represent, have no equivalent in the nonmilitary sector.

Recommendation: ONR should continue to fund and nurture long-range marine research and technology development. These efforts should be coupled with the education and training of scientific and engineering personnel in ocean science and technology.

STATUS OF TECHNOLOGY TRANSFER AT ONR

Finding: Federal agencies are mandated by public law to transfer technology (see Appendix C). The transfer of ocean science and technology within the Navy and to other government agencies, and to a large extent, to academia, appears to be adequate. Technology transfer to the nonmilitary commercial sector, by contrast, is clearly inadequate. This inadequacy is particularly evident in the transfer of technology to major U.S. corporations that lack a history of involvement with ONR and to small companies (less than 100 employees and less than $30 million in revenues) of all types.

Representatives of marine industries indicated to the committee that there is little direct involvement by ONR in commercial offshore R&D activity. An examination of the few measures of performance available (e.g., participation by ONR in cooperative R&D agreements, number of patents licensed) seems to support this view (see Chapter 3).

Recommendation: ONR should allocate sufficient resources to ensure the success of technology transfer to the domestic nonmilitary sector in ocean science and technology.

TECHNOLOGY TRANSFER AT ONR: THE ORGANIZATION

Finding: Even though an organizational structure apparently exists to facilitate domestic technology transfer by ONR, the existing process is primarily *ad hoc* and reactive rather than proactive.

Industries that do not have a connection to ONR find it difficult and costly to gain access to information available at ONR. The perception is that there is valuable technology at ONR but that existing mechanisms are not adequate to promote the development of this technology for commercial purposes (see Chapter 3). For these and other reasons, simply introducing financial or personnel management policies may fail to stimulate the technology interchange desired. There is a need for a new organizational mechanism that acknowledges the private sector as the best judge of what technology it needs, at what cost, and on what timetable (see Chapter 5). ONR does not possess the experience and perspective required to make such determinations without significant input from the user community.

Recommendation: ONR needs to take a more proactive role in domestic technology transfer in ocean science and technology. This can be accomplished using a combination of strategies, including organizational realignment, electronic databases, newsletters, sponsored forums and workshops, professional association meetings, personal communication among principal investigators, and funding incentives within ONR for programs that facilitate commercial product development. The existing programs intended to promote communication between ONR and the nonmilitary sector should be used to determine industry needs.

TECHNOLOGY TRANSFER AT ONR: THE INDIVIDUAL

Finding: Few incentives apparently exist within ONR to promote domestic technology transfer at the level of administrative program managers and investigators.

Investigators both within and outside of the Navy are motivated to produce superior research or develop new technology so they may receive continued funding or peer recognition. Similar inducements do not exist to leverage R&D efforts for application beyond their originally intended use. ONR investigators are well intentioned, but to take further advantage of R&D expenditures, additional incentives are required to encourage an increased focus on technology transfer (see Chapter 5). The importance of exploiting (or leveraging) technology must become a performance objective of the entire ONR organization. As the principal executive of ONR, the Chief of Naval Research needs to create plans for the transfer of technology with specific objectives and milestones for accomplishment. Although it is beyond the purview of this study to recommend specific program goals and levels of performance to ONR, these plans should reflect a program-wide priority on technology transfer to the nonmilitary sector. Progress toward achieving these objectives should be managed like any other development project and progress should be reported on a regular basis. Individual performance objectives should be established, beginning with top ONR executives and including all team leaders and laboratory investigators. Individuals should be rewarded or recognized on the basis of achievement measured against these objectives. To ensure the success of technology transfer, effective training will be required to enable all employees to understand the goals and mechanisms of a successful technology transfer program.

Recommendation: Incentives need to be provided at the program level, and measures of performance established at the executive level, to promote domestic technology transfer. The Chief of Naval Research needs to provide executive leadership and operational training at all levels of the organization to implement an effective technology transfer policy.

1

Introduction

Technology transfer from the federal defense sector to the domestic nonmilitary sector is a goal supported by several administrations and mandated by more than a decade of legislation (Appendix C). The use of military technology for nonmilitary needs (i.e., defense conversion), and the development of new military technologies in conjunction with industry for joint benefit (i.e., dual use) can provide cost savings and improve efficiency both in the Department of Defense (DOD) and in the private nonmilitary sector. Savings from reducing the size of the military could then be used to stimulate the U.S. economy (Naval Research Advisory Committee, 1993). The Clinton administration supports a technology policy intended to strengthen U.S. industrial competitiveness, create high-quality jobs, coordinate management of technology across all government agencies, create partnerships between the public and private sectors, and redirect the nation's technical resources to civilian uses (Naval Research Advisory Committee, 1993).

The purpose of the DOD domestic technology transfer policy, as stated in DOD Report 3200.12-R-4, is "to achieve the maximum national benefit from DOD scientific and technical efforts" (DOD, 1988). Report 3200.12-R-4 lists several policy statements supporting this goal:

> 1. Encourage the dissemination of scientific and technical information, data and know-how developed by or for the Department of Defense to State and local governments and to the private sector, consistent with the requirements of U.S. national security.
>
> 2. Promote the sharing of technology that fosters the advance of science or that has commercial potential and thus should be employed to best advantage for the security and socioeconomic well-being of the United States.

3. Support coordination between the industrial, academic, and Government R&D (research and development) activities of the United States by cooperating in the sharing of plans for future research efforts and the sharing of facilities as appropriate.

4. Support cooperative efforts to stimulate industrial innovation, especially in small businesses.

5. Support and encourage the exchange of scientific and technical personnel among academic, industry, and the DOD laboratories.

6. Support the domestic technology transfer process as an integral part of the R&D effort and incorporate domestic technology transfer objectives into the mission of each appropriate R&D activity.

7. Encourage domestic technology transfer in the work place through its recognition in position descriptions, in promotion policies, in monetary awards, and in performance evaluations for appropriate scientific and engineering personnel.

8. Ensure that R&D activities have at least one full-time equivalent position responsible for performing the functions of an Office of Research and Technology Applications (ORTA) at any activity having over 200 full-time equivalent professional scientific, engineering and related technical personnel. A full-time position for any activity with less that 200 professional scientific and engineering personnel is optional.

9. Ensure that domestic technology transfer functions do not compete substantially with similar services available in the private sector.

10. Ensure that the Domestic Technology Transfer Program does not conflict with export control regulations, policies governing militarily critical technology, policy requirements of recouping DOD nonrecurring costs, or any of the responsibilities and procedures for technology transfer control in DOD Directives, Instructions, and publications . . . .

11. Identify and encourage persons to act as conduits between and among Federal laboratories, universities, and the private sector for the transfer of technology developed from federally funded R&D efforts.

12. Ensure that State and local governments, universities and the private sector are provided with information on the technology, expertise, and facilities available in Federal laboratories.

Source: Department of Defense (1988).

To ensure that these 12 policies are carried out and to comply with Public Law 96-480, DOD 3200.12-R-4 required that 0.5 percent of the total research and development (R&D) budget for each DOD budget component be used to promote domestic technology transfer (DOD, 1988). DOD 3200.12-R-4 also stated that a waiver could be obtained from Congress at the time of budget submission if alternative methods of conducting technology transfer were provided. Subsequent changes to this provision were affected by enactment of Public Law 101-189, which substituted language referring to any specific level of funding expressed as a percentage of the R&D budget with "each Federal agency which operates or directs one or more Federal Laboratories shall make available sufficient funding . . . to support" technology transfer. The level of funding actually committed to facilitating technology transfer is therefore variable and is one indicator of the Navy's commitment to accomplish this important goal on a year-to-year basis.

Despite enactment of legislation and programs to encourage and even mandate technology transfer, the defense industry as a whole has not had a high success rate in defense conversion (Naval Research Advisory Committee, 1993). The most successful technology transfer efforts have involved aerostructures, as the needs of the commercial aerospace market are similar to those of the defense market. In areas without such a clear link to defense, there has been less success in transferring technology (Naval Research Advisory Committee, 1993). Most marine industries fall into the latter group. Information about the needs of the private marine sector does not commonly reach the Navy's primary producer and sponsor of marine R&D, the Office of Naval Research (ONR). Likewise, information about marine technologies currently available and under development at ONR is not adequately conveyed to nonmilitary interests. This lack of two-way communication, matching the "solutions" that potentially exist at ONR with the "problems" of the marine industry in the nonmilitary sector, forms a major impediment to effective technology transfer.

In response to a request from the Office of Naval Research (Appendix A), the Ocean Studies Board (OSB) of the National Research Council (NRC) formed the Committee on Alternative Uses of Naval Technology. The committee was requested to produce a report detailing (1) how ONR now interacts with industry, (2) how those avenues of interaction may be improved, and (3) future areas of technology research that may be appropriate for ONR to pursue, which might have applications to interests outside the Navy. The committee did not discuss specific areas of future basic research for ONR to pursue because the OSB has provided such advice in more than 12 recent reports to ONR (e.g., NRC, 1991, 1992a,b, 1993a,b,c,d,e, 1994). The committee focused its efforts on establishing the future technology needs of a major segment of the nonmilitary, industrial sector. The phrase "ocean science and technology development" is used throughout this report to denote hardware, software, patents (in process and issued), as well as scientific research and resultant knowledge.

Members of the committee have considerable knowledge of marine science and technology issues (Appendix B). The committee invited several ONR researchers, as well as representatives of key marine industries, to present their perspectives on the status of marine research and technology transfer. Three meetings were held to provide a forum for this exchange of information. The first meeting included presentations by ONR personnel regarding marine technologies currently available and under development. The second meeting assembled representatives of several marine industries and agencies to give their views on technology needs in the near future and the current status of ONR technology transfer efforts. The final meeting focused on information exchange by means of electronic databases. From these discussions the committee formulated four findings with corresponding recommendations.

Chapter 2 presents an overview of areas of marine technology development within ONR. Chapter 3 examines existing technology transfer programs in ONR and elsewhere in the federal government. Chapter 4 discusses present and future needs of several marine industries and evaluates the potential for ONR programs, outlined in Chapter 2, to address those needs. Processes and approaches to improve technology transfer within ONR are discussed in Chapter 5. Chapter 6 presents the committee's findings and recommendations.

2

Review of ONR Technology Research Programs

The Office of Naval Research (ONR) is divided into program codes, each with a separate research focus (Figure 1). Those with particular relevance to ocean science and technology development are ONR 32 (Ocean, Atmosphere and Space Science and Technology), ONR 33 (Engineering Materials and Physical Science and Technology), and ONR 34 (Personnel Optimization and Biomolecular Science and Technology). ONR 36 (Industrial Programs) is responsible for technology transfer for all ONR program codes. ONR also funds activities of the Naval Research Laboratory (NRL). Programs at NRL are similarly divided; a program of particular relevance to the marine industry is NRL 7000 (Ocean and Atmospheric Science and Space Technology).

Most ONR-sponsored ocean research and technology development is conducted within the Ocean, Atmosphere and Space Science and Technology Department (ONR 32). The mission of ONR 32 is to provide the scientific and technological base that will maintain and expand the operational superiority of the Navy and the Marine Corps in the ocean, atmosphere, and utilization of space. ONR regards this core area as helping the Navy to "win the environment." Conducting research and developing technology to help U.S. naval forces obtain a tactical operational advantage is a major focus for ONR. This effort includes all areas of ocean science and engineering, from sensing and systems to modeling and prediction.

Divisions within ONR have recently been vertically integrated to facilitate the transition of basic and applied research from the "lab bench," through exploratory and advanced development to the "marketplace," which for the Navy is the fleet. ONR is expanding its efforts to involve science and technology team

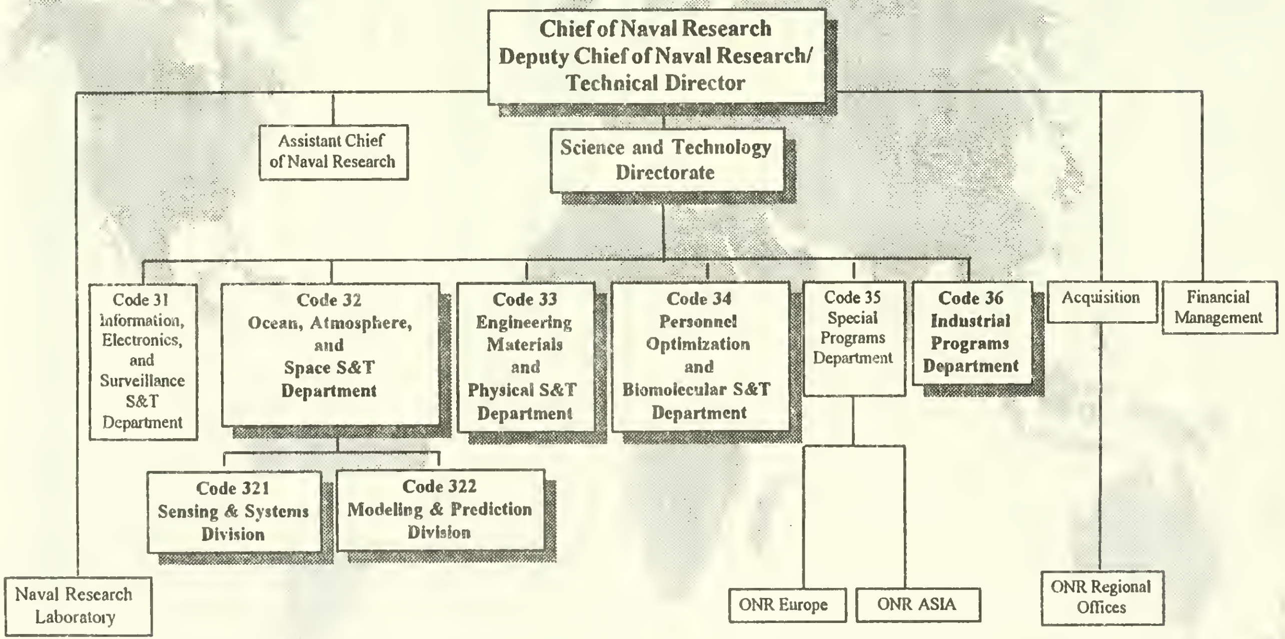

Chief of Naval Research
Deputy Chief of Naval Research/ Technical Director
Assistant Chief of Naval Research
Science and Technology Directorate
Code 31 Information, Electronics, and Surveillance S&T Department
Code 32 Ocean, Atmosphere, and Space S&T Department
Code 33 Engineering Materials and Physical S&T Department
Code 34 Personnel Optimization and Biomolecular S&T Department
Code 35 Special Programs Department
Code 36 Industrial Programs Department
Acquisition
Financial Management
Code 321 Sensing & Systems Division
Code 322 Modeling & Prediction Division
Naval Research Laboratory
ONR Europe
ONR ASIA
ONR Regional Offices

FIGURE 1 Organizational chart for the Office of Naval Research (ONR). Source: Office of Naval Research.

leaders in the operational exercises of the fleet, providing an opportunity for ONR staff to gain a better understanding of the needs of their primary customers. This is also facilitated by teaming the federal funding category 6.3 (advanced development) managers with the 6.1 (basic and applied research) and 6.2 (exploratory development) managers.

ONR develops many products for the Navy that have potential nonmilitary application. These products include *tangible technology* as well as *information* contained in databases and interpreted through models. ONR-supported research and development activities have resulted in a large amount of tangible technology and information, including instruments and sensors, platforms, systems engineering methods, information technology, algorithms, models and simulations, and databases, developed by ONR 32 (Steve Ramberg, ONR, personal communication, 1995; see Tables D1-D5 in Appendix D).

A number of key areas with high potential for dual-use applications are described in more detail in subsequent sections. These include areas such as remote sensing, computer modeling, deep-sea technology, salvage and construction methodologies, and coatings and materials development.

REMOTE SENSING

Remote sensing R&D at ONR 32 is housed mainly in the Sensing and Systems Division (321), but aspects are also addressed in the Modeling and Prediction Division (322). "Sensing" includes detection of an acoustic, optic, chemical, physical, or biological parameter of interest. "Remote" sensing is often associated with satellites or aircraft, but also includes the use of underwater acoustics. Remote sensing refers to the technology that detects the signal, as well as the methodology that processes and models the signal.

The Sensing and Systems Division (321) focuses on technology development in the following areas:

- Ocean acoustics
- Space and remote sensing
- Sensing-information dominance
- Coastal dynamics
- Sensors, sources, and arrays
- Ocean engineering and marine systems
- Undersea signal processing
- Littoral surveillance and systems
- Tactical sensing support

The Modeling and Prediction Division (322) also supports a broad agenda of scientific inquiry and technology development in areas of environmental optics, physical oceanography, biological and chemical oceanography, ocean modeling and prediction, atmospheric modeling and prediction, high-latitude dynamics, tactical environmental support, marine geology and geophysics, and marine meteorology.

Acoustic modeling and tomography/imaging play important roles in the development of active and passive systems for mine and antisubmarine warfare. Electro-optical and electromagnetic (EO/EM) clutter models, automatic target recognition, and techniques related to adapting space sensor information are used in algorithms for environmental models. Nonacoustic undersea sensors and related signal processors are under development for application to undersea, mine, and expeditionary warfare. New technology related to ship tracking is being developed. Coastal ocean models and enhanced bathymetric mapping techniques aid in coastal operations and navigation. New acoustic sources and arrays allow better environmental characterization and target recognition. The development of specialized research platforms, including remotely operated vehicles, should result in increased capabilities in littoral areas. The development of technologies for undersea and shallow water acoustic sensors will aid in tactical data acquisition, offensive mining, mine countermeasures, and explosive ordnance disposal. New optical technologies are being used to examine ocean surface and marine boundary layers for three-dimensional modeling of the dynamics of marine populations, fate and transport of pollutants, and natural environmental changes in the ocean.

COMPUTER MODELING

ONR, primarily through activities at NRL, has developed an impressive ability to provide real-time predictions for the Navy using global, regional, and (to a lesser extent) coastal modeling. Predictions using high-resolution, coupled atmospheric-ocean models are being developed. These models can predict circulation and atmospheric conditions in selected local areas (e.g., off the west coast of the United States). They make use of the most powerful computational platforms available. A wealth of software has been developed to (1) visualize model predictions, (2) manage large volumes of data, (3) integrate the data with the model predictions (e.g., data assimilation), (4) efficiently transfer and tailor the data to the user's needs, and (5) verify the model predictions. These integrated modeling and data management systems represent the state of the art.

The primary academic application for atmospheric and oceanic circulation models involves research into global and regional ocean circulation and meteorology. Research into air-sea interaction and its influence on long-term climatic change represents another important academic application. In the commercial sector the most important user groups include environmental and engineering consulting companies (e.g., firms interested in pollutant transport and fate modeling, circulation, physical forcing on offshore structures, dispersion of routine discharges, and disposal of wastes at sea), data brokers and value-added suppliers (e.g., data services that provide either prepackaged or customized data products, ship routing, and environmental forecasting for offshore operations), and firms that specialize in exploration, development, and transportation of offshore oil, gas, and minerals.

DEEP-SEA TECHNOLOGY

ONR has a long history of research and technology development for Navy application in the deep-sea environment. The primary commercial interests in this area are involved in offshore oil and gas exploration and production as well as pipeline operation and maintenance. Deep-sea mining is another potential application; activity in this area has been somewhat sporadic as the presently available technology has not made deep-sea resource development economically viable.

The discussion below should be considered only a sampling of the available and emerging science and technology at ONR that is applicable for transfer to deep-sea commercial interests. ONR science and technology applicable to non-military deep-sea operations are included in the following categories:

- Surface/subsurface seakeeping
- Fabrication techniques and materials
- Remote vehicle design and operation
- Environmental characterization
- Operational systems support

Surface/subsurface Seakeeping

For the design of ships and other seagoing platforms, ONR has conducted extensive research and developed a considerable body of technology in the area of naval architecture. Available data and models relate wind, waves, and hydrodynamic flow to forcing functions applicable to structural design and analysis. Techniques for the design of deep moorings with chains and cables have been developed. Some of the available and emerging ideas include mooring deployment methods, innovative mooring designs (e.g., S-tether), expendable moorings, slack cable dynamics, and models for cable/riser strumming. ONR has also developed methods for obtaining and maintaining a precise position in the water column or on the bottom by using remote/portable tracking systems.

Fabrication Techniques and Materials

The construction of structures and piping for the Navy is done within ship and submarine construction programs. The Navy has developed a significant expertise in welding, particularly of high-strength materials, and materials testing in support of these programs. The Navy is exploring innovative methods to reduce weight and lower cost; these methods include the use of high-powered lasers for welding and cutting and for application of surface coatings. One such application on Navy ships involves fabrication of corrugated steel panels (termed LASCOR) that provide high strength-to-weight ratios and significant fire retardation properties. Techniques under development include *in situ* repair and fabrication using fiber-optic delivery of laser energy. The science and technology efforts on advanced composite materials for marine applications are aimed at high-strength materials that are lightweight and damage resistant. Through considerable research into marine corrosion and biofouling, the Navy has also developed new mitigation techniques (see Tables D6 and D7 in Appendix D) that could benefit the entire marine industry.

Remote Vehicle Design and Operation

With its strong background in undersea vehicle design, ONR has under way numerous efforts applicable to the development of deep submergence and remotely operated or piloted vehicles. Vehicles such as the MEDIA/JASON family and the ALVIN are examples. Additional programs support a new group of vehicles called AUVs (autonomous undersea vehicles). These new designs would be untethered, remotely controlled, autonomously programmed vehicles, with both navigational and robotic capacities. These and similar technological developments are potentially exploitable by the commercial marketplace:

- Sensors, including acoustic, laser, and magnetic systems
- Structures, including remotely operated vehicle (ROV) designs and methods, materials, and handling
- Cabling/communications, including fiber-optic tow cables and acoustic communications
- Autopilot/control, including laser gyros, fiber-optic sensors, and motion compensator systems
- Power/energy systems, including energy-efficient thermal and electrical systems such as "wick" combustors and lithium-seawater batteries
- Thrusters/propulsors, including advanced, significantly quieter and more efficient thruster designs
- Robotics, including manipulators, tools (e.g., rock drills), nonlinear control systems, adaptive sampling, and mini-winches
- Data assimilation/display, including data fusion techniques and virtual displays
- Simulators, including distributed and interactive simulators for design and training

Environmental Characterization

Scientific research and technological development applicable to deep-sea operations include techniques for bottom mapping and sub-bottom profiling (as well as existing databases), understanding sediment and its properties, and modeling suspended sediment distribution. Ocean bottom seismometers are available for monitoring seismic activity at potential operating sites. Programs for *in situ* measurement and modeling of the ocean environment discussed earlier complement these activities.

Operational Systems Support

The broad category of operational systems support highlights technologies that have the potential to improve efficiency and enhance safety and environmental compliance of ongoing or future undersea and surface operations. These technologies would include system monitors and sensors for metering flow using nonobtrusive methods or for detecting leaks or determining status and projecting failure. ONR efforts in the area of condition-based maintenance (i.e., maintenance systems capable of adjusting to real-time system needs as opposed to simply following predetermined schedules) could be applied to reduce operating costs and forecast potentially catastrophic failures. ONR is developing advanced hydrodynamic design methods that can be used to increase efficiency and lower the cost and weight of pumps and pump systems. Other technologies under development include long-lived power and energy sources that can operate in the deep ocean, including both thermal (wick and H_2/O_2) and electric (rechargeable batteries and fuel cells) systems.

The greatest obstacle to future developments in remote vehicles is clearly the lack of cost-effective power and energy systems that can operate for long periods underwater. ONR breakthroughs in this area would constitute a major contribution to deep-sea technology development.

OCEAN SALVAGE OPERATIONS

Technology for marine salvage and related activities can be divided into five areas covering the following capabilities:

- Bottom and sub-bottom characterization
- Object surveillance, location, and identification
- Work environment and life support (including deep-water diving tables)
- Work systems
- Greater autonomy, improved training, and simulation

Technologies for bottom and sub-bottom characterization include acoustical systems and optical systems configured for side-scan and wide-swath mapping. Other technologies for object surveillance, location, and identification use monochromatic laser-line scanners, synthetic aperture sonar, and magnetic anomaly detection to identify mine-like objects.

Research into increasing efficiency in the work environment includes underwater light propagation and miniaturization of acoustic sensors for hand-held units. Underwater life-support systems under development include self-contained breathing apparatus and rebreathing systems. Work systems currently used in the underwater workplace may be improved with research into fiber-optic lines for high-bandwidth data transmission, special couplers and optical signal processors for undersea use, and diver work tools that are powered by seawater and are resistant to corrosion and contamination.

ONR is developing high-speed data communications for autonomous vehicle and other undersea naval applications and small, efficient undersea power sources. Real-time feedback control systems that adapt both to a changing environment and to knowledge "learned" in real time will provide efficient use of resources and immediate data collection.

Simulators that operate in tandem over networks are in use for training and for design performance evaluation of new concepts. As simulations become more complex and the amount of required common information grows for linked simulations (e.g., background weather linked to a navigational simulator), the need for standards of intersimulator control becomes more critical. Increasingly accurate and fast replication of complex situations in "virtual environments," possibly by linked simulators, will provide a basis for comprehensive training and mission rehearsal in the future.

This technology could be of value to any company interested in underwater construction and repair (e.g., oil and gas platform construction, shipbuilding, submersible development). ONR has made no formal effort to inform these industries of the opportunities for technology transfer and the benefits it represents. The committee concluded, based on the considerable list of technological developments provided by ONR staff (Appendix D) and the apparent lack of involvement of marine industry representatives with ONR, that the amount of technology available far outweighs the amount successfully transferred.

COATINGS AND MATERIALS

The annual costs to the Navy for biological fouling and corrosion are $1 billion and $2 billion, respectively. To combat these two problems, ONR sponsors research on corrosion- and fouling-resistant coatings at NRL and several research universities. Many such coatings developed at NRL have recently seen wider use by the fleet. This trend should continue, especially given the increasing environmental restrictions on the use of certain, more traditional, coatings and coating solvents that may contain organotin compounds, chromates, or lead.

The amount of transferable technology in the coatings area (see Tables D6 and D7 in Appendix D), though already significant, is likely to increase because of regulatory constraints and the high-quality research supported by ONR. ONR also supports research on corrosion inhibitors and anodic protection (passivity) at NRL and several universities. Several additional projects sponsored through ONR's Small Business Innovation Research program involve possible sensor technology for detecting various forms of localized corrosion in marine environments. The potential for technology transfer should increase in the future because of (1) the environmental concerns mentioned above (e.g., how Navy activities affect the environment or workplace), and (2) the Navy's continued desire to prolong the life of ship systems in the extreme conditions of the marine environment.

The high-quality, scientific research and the technology development supported by ONR are an important component of the Navy's efforts to maintain combat readiness and tactical advantage. The committee recognizes that R&D supported by ONR is of vital importance for fleet effectiveness and national defense. Many of the marine research efforts described above, and the expertise they represent, do not exist outside ONR-supported programs. It is, therefore, unfortunate that few of the products discussed thus far have been successfully transferred to the nonmilitary sector. Much of the value has yet to be discovered by the commercial user. Tangible products are generally the first to be transferred, although slowly. Despite an apparent broadening of customer need for hardware and for interpreted information, there is no formal mechanism in place to transfer models and information to users outside the defense industry.

3

Status of ONR Technology Transfer Programs

This chapter provides an overview of ONR efforts to transfer technology. A successful technology transfer program used by the National Aeronautics and Space Administration (NASA) is discussed to provide perspective. The background to the present policy on technology transfer is provided by the Federal Technology Transfer Act of 1986, Public Law 99-502 (Appendix C).

In response to Public Law 96-480 and Executive Order 12591 (Appendix C), the Undersecretary of Defense for Acquisition in 1988 issued a Domestic Technology Transfer (DTT) Program Regulation to "ensure the full use of the nation's federal investment in research and development (R&D), stimulating improved use by state and local governments and the private sector" (DOD, 1988). A specific policy goal is to "promote the sharing of technology that fosters the advance of science or that has commercial potential and thus should be employed to best advantage for the security and socioeconomic well-being of the United States" (DOD, 1988). SECNAV INSTRUCTION 5700.16 of 27 October 1989, assigns the Chief of Naval Research (CNR) responsibility for military-civilian domestic technology transfer for the U.S. Department of the Navy.

ONR TECHNOLOGY TRANSFER MECHANISMS

In accordance with the regulation and instruction, the CNR issued OCNR Instruction 5700.1 on 24 July 1991 to implement the policy and procedures for the Navy DTT program. The numerous mechanisms formally established to encourage and promote technology transfer are summarized below.

Navy Technology Application Assessment—A Navy Technology Application Assessment (NTAA) is a documented summary describing the application of technology developed by ONR that is potentially useful to state and local governments or the U.S. private sector. NTAAs are released to the National Technical Information Service.

Federal Laboratory Consortium for Technology Transfer—The Federal Laboratory Consortium (FLC), including ONR laboratories, is supported by its component agencies and responsible to the National Institute for Standards and Technology of the Department of Commerce. The FLC identifies and facilitates technology transfer. The level of support contributed by the Navy to the FLC is determined by the CNR (presently 0.008 percent of the total Navy R&D budget).

Office of Research and Technology Application—An Office of Research and Technology Application (ORTA) has been established at each Navy laboratory for managing and coordinating DTT activities. Each organization within DOD must establish ORTA functional units of at least one employee's full-time effort (FTE) if there are between 200 and 1,000 technical personnel and at least two FTEs if more than 1,000 technical personnel are employed. ONR headquarters manages and assesses the ORTA process at each laboratory. Funding support of ORTAs comes from internal laboratory overhead or return on invention licensing and royalties.

Cooperative Research and Development Agreement—Cooperative Research and Development Agreements (CRDAs) are agreements between a federal agency or agencies and nonfederal parties to perform cooperative R&D. A CRDA is a legal mechanism for federal agencies to work with private companies to exploit government technology and invention while protecting the title and licensing rights of each party. The federal agency provides personnel, services, facilities, equipment, and other resources with or without reimbursement. The nonfederal party provides similar resources but receives no government funds.

Individual Awards and Compensation for DTT Contributions—The Navy offers individual awards and compensation to federal employees who make significant contributions to Navy DTT. Eligibility for patent license royalties is an additional award mechanism. In addition to the above formal DTT mechanisms prescribed by regulations, ONR has several other means for facilitating technology transfer, including the various types of industrial agreements and programs discussed below.

Industrial Agreements Other than CRDAs—In addition to CRDAs, ONR uses other agreements with industry that promote technology transfer. These agreements include contracts and grants for which 100 percent of the funding is provided by the federal government, and cooperative agreements involving cost sharing (e.g., Technology Reinvestment Programs, called TRPs). These efforts, in general, focus on defense needs. Some of the technologies developed, however, may have potential application in the nonmilitary sector. The industry partner does, in those instances, have a direct opportunity to market the technology.

Small Business Innovation Research—The Small Business Innovation Research (SBIR) program is intended to encourage small business to meet specific needs identified by federal agencies. The process often involves a Navy laboratory or headquarters component working with a small business that accomplishes technology transfer. The business retains the option for commercializing the product for use in other sectors.

Manufacturing Technology Centers of Excellence—Manufacturing Technology Centers of Excellence facilitate the development of manufacturing technology to address Navy applications. The centers provide a direct opportunity for industry to collaborate and exploit technology developments for commercial applications.

Industrial Consortia—Industrial consortia may involve collaboration by several competitors to advance the overall capability of industry in a given field. A successful example is the industrial consortium associated with the Navy Powertrain Technology Center, in which both defense and commercial industries participate.

Conferences and Symposia—Technical conferences and journals are excellent opportunities to share research results and transfer technology. Such outlets form the basis for documenting the evolving state of scientific knowledge related to ONR-supported programs.

Patents and Licensing Agreements—Patents held by the government can be exploited for commercial application through licensing arrangements. Technology is therefore made available while generating revenue.

Coordinating Committees—ONR uses coordinating committees as a formal mechanism for working with other government agencies (e.g., the National Oceanic and Atmospheric Administration). These committees provide an opportunity for mutual planning and benefit.

TECHNOLOGY TRANSFER AT NASA

To achieve a better understanding of the variety of mechanisms used to facilitate technology transfer in other federal agencies, the committee examined the NASA DTT program. The stated mission of the NASA DTT program is to focus directly on industrial development and growth to secure national economic competitiveness for space technology. The Navy's mission of national defense is significantly different from NASA's mission of space exploration; however, the mechanisms and procedures used by NASA may provide useful models and lessons for ONR technology transfer efforts.

NASA has recently undergone a significant change in position regarding domestic technology transfer. This change was driven by a top-down formulation of strategic goals for achieving the stated mission of NASA's DTT program. One of the goals is to share "the harvest of space technology with the U.S. industrial community" through domestic technology transfer (John Mansfield, NASA, personal communication, 1995). The significance of this approach is the priority attached to DTT and the high level of commitment to achieving it. Along with the strategic goal, quantitative objectives (or metrics) have been set to provide NASA a target for expected levels of performance. Performance is then measured against these goals by examination of detailed information collected for this purpose (e.g., number of inquiries received on the Internet, number of commercial partnerships, financial contribution to commercial partnerships).

Keys to the success of the NASA plan for facilitating technology transfer include specific actions and activities in six areas:

- **Policy**—NASA established new policies for technology investment; partnerships; SBIR grants; federal, state, and local alliances; and R&D procurement.
- **Metrics**—NASA developed a set of commercialization measures (or metrics) of performance. Data collection tools and reporting processes were also developed.
- **Marketing**—NASA targets specific technology segments, as well as broad-based technology diffusion, using a variety of marketing mechanisms (e.g., industrial consortia, NASA Advanced Materials Centers, the Tech 2005 Conference, and *Innovation Magazine*).
- **Business Practices**—NASA developed seven principles of operation designed to be compatible with the way the private sector conducts business (e.g., contractor-developed technology commercialization, small business technology development, and regional alliances with industry and universities).
- **Training and Education**—NASA employees in field centers and headquarters are trained to conduct commercial technology transfer.
- **Electronic Network**—An electronic network links NASA field centers and headquarters with each other and with the commercial sector.

The new NASA initiatives appear to have achieved a clearer focus on the DTT process and results. Since 1992 technology partnerships have increased from 328 to more than 3,000 and investments have increased from $174 million to more than $450 million (John Mansfield, NASA, personal communication, 1995).

OBSERVATIONS REGARDING TECHNOLOGY TRANSFER AT ONR

The focus of ONR activity is improvement of the defense posture of the nation; therefore, much of the technology transfer effort is in direct support of that mission. The commercialization of ONR-developed technology is consequently dominated by defense industry participants.

There are mechanisms presently in place to facilitate domestic technology transfer. The question remains, however, "How well does the process work?" For a narrow range of industrial needs and a small number of technology areas, the process seems to function well. The connections with the defense industry are well-established and technology transfer occurs seamlessly. One way that ONR research and development is indirectly transferred to the nonmilitary sector is through the adoption of Navy specifications based on ONR-supported activities (e.g., marine vessel design) by engineers outside the Navy. In certain science areas (e.g., signal processing, acoustics, and materials) the results of ONR-sponsored research are well disseminated through published technical journals, conferences, and symposia. There remains, however, a sizable segment of industry that could use ONR technology for nonmilitary purposes but is poorly served by the present technology transfer process. ONR possesses significant technology that warrants commercialization (see Chapter 2), but the process for identifying and exploiting that technology is not effective.

The burden of transferring technology to the private sector falls heavily on the team leaders of the ONR divisions. These leaders are skilled, technically competent scientists with an excellent understanding of fleet needs. For knowledge of the potential industrial market for ONR products in the nonmilitary sector, ONR team leaders must rely on the Industrial Programs Department (ONR 36). ONR 36, however, makes insufficient effort to develop an understanding of the needs of nonmilitary users or to market the products of marine technology research. The department has focused more on obtaining technology than marketing or transferring ONR technology to the nonmilitary sector. This emphasis on obtaining technology has resulted in a decidedly one-way exchange of information. This arrangement is of little benefit in terms of informing the in-house scientists and managers (i.e., the individuals responsible for meeting the requirements of the various government mandates) about the technology needs of the nonmilitary, industrial sector.

In ocean science and technology, for example, a large segment of U.S. industry that could benefit from ONR-sponsored technology has little or no interaction with ONR. This segment includes both major corporations (e.g., Chevron USA and Amoco in the oil and gas industry) and small companies (i.e., companies with annual revenues less than $30 million or fewer than 100 employees). Evidence of this lack of involvement appears in several areas listed below. The committee did not develop, nor does it recommend, specific values for the metrics listed below (only a subset of potentially useful measures), and it did not conduct quantitative analysis of such measures. Such standard setting should be conducted by ONR upper management. ONR's performance in technology transfer should be comparable to the overall performance of DOD in technology transfer (i.e., the technology transfer efforts of any DOD R&D program, as gauged by any given metric, should be roughly proportional to that program's share of the overall DOD R&D budget). Indicators of the effectiveness of present ONR technology transfer efforts include the following:

- **Participation in CRDAs**—Of the 413 CRDAs involving DOD in 1993, ONR participated in 80, approximately 19 percent (David Rossi, ONR, personal communication, 1995), which compares favorably with ONR's portion of the DOD budget (18 percent). Only seven of the 80 ONR CRDAs involved offshore technology, however, (and most of these seven involve short-term consulting or ONR facilities rental). The total number of CRDAs involving ONR has increased to more than 280 as of July 1995 (David Rossi, ONR, personal communication, 1995). Although this increase in the cumulative number of CRDAs in which ONR is involved may suggest a significant improvement in technology transfer in this area, specific information on the type of CRDAs represented (i.e., by category such as ocean science, aerospace, etc.) was not available for the post-1993 period. This lack of specific information makes comparison of ONR performance before and after 1993 difficult, even for this single metric.
- **ORTA marketing tools**—The main marketing mechanism used by ONR is the CRDA (see above). Examination of brochures and advertisements distributed by ONR suggests that ONR's interest in ORTA is more as a vehicle to market ONR laboratory facilities and personnel than to transfer ONR knowledge and technology to the private sector for commercial development.
- **Proliferation of terms**—Broad understanding of technology transfer policy appears to have been hampered by conflicting rhetoric (e.g., conversion, uni- and bi-directional transfer, dual-use, spin-on, spin-off, technology-push, market-pull). Several responsible ONR officials are still uncertain about what qualifies as "domestic technology transfer."
- **Low number of patents licensed**—Less than 2 percent of patents awarded to DOD are in ocean science and technology (80 of 4,600), despite the fact that ONR (i.e., Navy S&T) funding accounted for approximately 18 percent of total DOD S&T funding in 1995.
- **Lack of effective marketing programs**—ONR has designed a pilot program at the University of Maryland to use MBA students and faculty to identify technologies with promise for commercialization and to perform market research.

No quantitative results from this pilot program were presented to the committee; therefore, its effectiveness was impossible to judge.

- **Lack of matching grants**—ONR does not appear to be involved in any state or local matching grant programs to promote industrial diversification.
- **Presence of ONR barriers**—The majority of small and large companies and venture capitalists without roots in defense contracting do not pursue technology transfer with ONR for a variety of reasons (e.g., perceived excess costs of the effort, transfer often hindered by ONR, ONR insensitivity to the crucial importance of timeliness in the international competitive marketplace, exclusion from the process by administrative edict). Of 18 small innovative companies known by the committee to be engaged in offshore technology, none participate with ONR in joint projects or technology transfer (John Johnson, Perry Tritech, personal communication, 1995). One of the largest companies engaged in offshore oil, gas, and pipeline operations (Chevron USA), has no history of technology transfer with ONR (David Clementz, Chevron Petroleum Technology Company, personal communication, 1995).

ONR has a decidedly mixed record in transferring technology to the potential nonmilitary commercial user. Conversely, transfer to the academic community seems to be well developed, making use of the traditional *ad hoc* procedure of shared interests between scientists in the respective organizations. The transfer is generally on a one-to-one basis and is fostered by each community. The transfer normally begins and is nurtured by presentations at professional society meetings and forums.

Transfer to the commercial sector, however, appears to be marginal at best. The Oceanographer of the Navy has signed a memorandum of understanding with the National Oceanic and Atmospheric Administration to allow civilian access to the Naval Oceanographic Data Distribution System; however, this understanding is a recent initiative and the commercial community appears to be essentially unaware that access is possible.

Few cooperative agreements exist with the commercial sector. The only ONR CRDA that could be found in the area of computer modeling was completed in February 1995 with KTAADN, Inc. The purpose of this CRDA was to perform systematic testing and application of high-resolution meteorological modeling while assisting the U.S. effort to defend the America's Cup. Despite being a high-profile activity and possessing positive public relations value, this cooperative effort is not likely to generate new growth in the economy. Recent attempts to develop such cooperative relationships have met with mixed success. It is clear from this experience that ONR and NRL do not have effective procedures for initiating, implementing, and monitoring such agreements. Examples of successful technology transfer involving ONR appear to be limited to ventures based on person-to-person contacts in which both individuals share a sense of gain. Formal efforts to declassify existing Navy databases for the collaborative use of the ocean science research community are a primary example of the type of mutually beneficial exchange enjoyed by academia and naval research personnel. Reports and initiatives in this area, however, make no provisions for the nonacademic, domestic commercial sector (e.g., MEDEA, 1995).

Transfer of ONR-supported technology to the academic community appears, in summary, to work well for both groups. The same cannot be said, however, for transfer from ONR to the commercial sector. Despite the high potential for transfer between ONR/NRL and the commercial sector, and the Navy's existing mechanisms to perform the transfer, the exchange is relatively low and episodic at best. The principal reason for this poor exchange appears to be a lack of ONR/NRL commitment and incentives to maintain the interaction necessary to foster vigorous technology transfer with the commercial sector.

The Chief of Naval Research should make it clear that technology transfer is a major goal for the Department of the Navy, and therefore for ONR. Technology transfer should become a part of the mission objectives for the Navy and be incorporated as an integral part of the Navy Strategic Plan. The elements of the technology transfer plan should be embraced by the senior management responsible for its development and implementation. Specific metrics in performance and scheduling should be established and reviewed quarterly by the Chief of Naval Research. Recognition and rewards need to be established at the level of the Chief of Naval Research to acknowledge the importance and accomplishments of efforts to promote technology transfer. Finally, the use of electronic networking and active participation in nonmilitary trade shows and professional meetings are absolutely vital to ensure a successful technology transfer program.

4

Industry Technology Needs for the Future

The Office of Naval Research (ONR) supports research and development (R&D) in several areas with potential for application outside the Navy. Many marine industries and other nonmilitary users could benefit from some product of ONR research (in such areas as coastal zone management, parks and recreation, shipping and shipbuilding, and commercial weather forecasting). The committee could not explore all possible applications of ONR technology but instead focused its attention on four important, potential user groups. The committee invited representatives of the oil and gas industry (i.e., exploration, production, and pipeline operation), fisheries, environmental companies, and marine equipment and service providers to present their views on the existing and future technology needs of industry. Because of their economic dominance, these four groups represent that segment of the nonmilitary, marine industrial sector that the committee concluded could benefit the most from future ONR-supported research and technology development.

OIL AND GAS INDUSTRY

Whether measured by payroll, value output, capital investment, geographic reach, or technical complexity, the offshore oil and gas industry (including exploration and production, as well as pipeline operation and maintenance) is this country's most significant commercial activity offshore. ONR is the most powerful American instrument for marine technology development. Cooperative effort, information interchange, and technology transfer between these two entities appear, however, to be intermittent and incomplete, at best. They are, at worst, nonexistent. There is a need for better mutual disclosure and technical interchange between ONR and the oil and gas industry to maximize private investment in the U.S. national interest.

Before addressing the reciprocal transfer of offshore technology between ONR and the private sector, it is helpful to review the existing state of the oil and gas industry with special regard to technology outsourcing and strategic partnering. Specific offshore technology needs can then be more effectively examined and understood.

There are two traditional technology strategies in the petroleum industry: (1) companies own all technology, having a full suite of internal capabilities (common among major companies); or (2) companies outsource (i.e., contract out) all technology needs and rely completely on outside suppliers (common among smaller independent companies). A third approach incorporating advantages of both strategies is now emerging in the industry. Some companies are beginning to adopt a strategy in which they own core technologies and outsource the remainder. This allows a company to retain highly focused, business-oriented R&D while relying on suppliers for other support. The change has been driven by cost/benefit analyses, rapid changes in technology, a redundancy and overcapacity of technology supply, formation of strategic business units within corporations, and an increased emphasis on international operations. This new technology acquisition strategy suggests that the offshore oil and gas industry might be open to technology transferred from ONR.

Strategic partnering between major corporations and smaller suppliers can be used to achieve alignment between two very different organizations. For strategic partnering to be successful, several factors must be present: (1) mutual trust, (2) multilevel relationships and commitments, (3) appropriate use of core competencies, (4) common goals, (5) cultural and strategic compatibility, (6) integrated decision making and information systems, and (7) open and frank communication (David Clementz, Chevron Petroleum Technology Company, personal communication, 1995). Historically, strategic partnerships have a low success rate (e.g., a study of 50 industrial alliances by Slowinski (1992) showed that only 50 percent lasted four years or more). This low success rate is primarily due to lack of compatible strategies, unclear or conflicting objectives and time frames, cultural barriers, inability to fulfill customer expectations, and lack of implementation plans and alliance management (David Clementz, Chevron Petroleum Technology Company, personal communication, 1995). The same problems may surface in interactions between ONR and the major oil and gas companies.

The major technology needs of the offshore oil and gas industry (i.e., exploration, production, and pipeline) can be divided into the following subsets:

- Environmental needs
- Floating drill platform needs

- Fixed drilling and production platforms and facilities needs
- Subsea completion needs
- Subsea pipeline needs

Environmental needs include baseline studies for environmental impact statements and quantification of the effects of oil and gas operations on the environment. These tasks require methods and instrumentation to measure several parameters such as the concentration of chemical compounds in the atmosphere, seawater, and seafloor sediment over representative periods of time. The amount of nutrients available and the size of coral, fish, shellfish, and mammal populations in the area and their fluctuations over time must also be documented. The methods and instrumentation used to establish baseline data are available now. The challenge is to design and install these systems to survive in the ocean over the required periods, providing continuous monitoring and data recording and transmission.

Drilling from a floating platform requires several unique abilities, including (1) accurate monitoring and forecasting of weather, sea state, and currents; (2) adequate mooring and station-keeping technology (including location and real-time monitoring of the bottom hole and use of global positioning systems and dynamic positioning for the surface platform); and (3) adequate methods to separate and dispose of wastewater and drilling fluid at sea. Drilling and production platforms need design criteria based on atmospheric and oceanographic conditions, stress and load analysis, soil shear strength, and consolidation of the underlying seafloor. Platform construction and maintenance presents its own set of challenges:

- Inspection and crack detection and repair at depths to 2,500 feet (some of which may be accomplished by remotely operated vehicles [ROVs])
- Use of autonomous underwater vehicles (AUVs)
- Underwater explosive cutting and welding technology
- Use of composite materials in topside structures and drill pipe and risers to reduce weight and increase resistance to abrasion, fire, sunlight, and salt water
- Use of paint and painting systems, both surface and underwater
- Use of deepwater pipeline connection systems (e.g., ROV and AUV) for both rigid and flexible pipe
- Use of space-frame and finite-element design techniques

Subsea completion of wells presents other unique requirements, including:

- Control systems
- Long-life autonomous power supplies
- Quick-acting valve operators and controls
- Pipeline and valve connection and monitoring

TABLE 1 Technology Needs of Offshore Oil and Gas Industries

Technology Area	Short-Term Need* 1995-1999	Long-Term Need* 1999-2010
Hydrate prevention	4.7	3.3
Flow metering	4.3	4.0
Subsea equipment	4.3	3.3
Flow lines	4.2	3.3
Extended-reach drilling/production	4.1	3.3
Risers	4.1	3.0
Drilling	4.1	3.5
Multiphase pumps	4.0	4.6
Workover	3.7	3.5
Produced fluid disposal	3.6	3.3
Structures	3.4	2.7
Extended-reach control systems	3.3	2.5
High-pressure systems	3.0	3.3
ROV systems	3.0	3.2
External corrosion protection	2.6	4.3
Water/gas injection	2.3	4.3

Source: National Petroleum Council (1995).

*NOTE: Average response of 10 major corporations to a 35-page questionnaire. Respondents were asked to rank needs as low (1), medium (3), or high (5).

- Subsea pumping, compression, and oil/gas separation systems
- Relocation beacons with remote triggering
- Acoustic, fiber-optic, and hard-wire data transmission

Subsea pipeline construction and operation requirements include installation methods, leak detection, fluid metering, oil and water cut monitoring, wall thickness monitoring, and methods for maintaining pipeline location.

A recent survey conducted by the National Petroleum Council (NPC), an industry association, outlined the technology needs of the oil and gas industry. The NPC survey indicates an average ranking of specific needs of 10 major companies. The survey contains important information regarding both short-term (the next five years) and long-term (1999-2010) industry needs, which are summarized in Table 1 (National Petroleum Council, 1995).

Overlap exists between the needs of the offshore oil and gas industry and areas of research supported by ONR. NRL 7000 (Ocean and Atmospheric Science and Space Technology) conducts research and development in many areas that have potential application to offshore petroleum activities (see Table D8 in Appendix D), including the following:

- Physics of seismic and acoustic energy interaction with seafloor topography and subsea floor
- Advanced electro-optic, electromagnetic, and acoustic techniques for mapping and imaging the seafloor and sub-seafloor and its variability
- Analysis and modeling of atmospheric processes on coastal, regional, and global scales
- Systems for shipboard tactical environmental data acquisition, management, and display
- Satellite data image analysis
- Simulation of atmospherics

ONR 33 addresses technology needs in environmental and materials science. Areas of R&D within ONR 33 that are directly applicable to oil and gas industry needs include the following:

- Separation of oily wastewater at sea
- Subsea construction technologies
- Monitoring methods for structures and coatings
- Environmental monitoring and modeling methods

Recent declassification of remote sensing data from defense satellites such the Navy's geodetic satellite GEOSAT has generated tremendous interest in both the petroleum and fisheries industry, as these new data allow greater accuracy in determining seafloor structure from observations of sea surface elevations. The offshore petroleum industry needs surface meteorologic data as well as bathymetric data and oceanographic data for many specific areas (e.g., the Malacca Straits, the South China Sea, the Gulf of Thailand, Scotland's northwest approaches, Ireland's western approaches, the Gulf of Mexico, coastal West Africa [Angola], and Sahkalin Island). If this type of meteorological and oceanographic data is made available to the industry, enormous amounts of proprietary data might be made available to ONR in exchange. The petroleum industry has spent millions of dollars, over several decades, to acquire detailed sub-bottom profiles (including subseafloor data to 500 feet), as well as data on seafloor structures, moorings, and relevant modeling technology (David M. Clementz, Chevron Petroleum Technology Corporation, personal communication, 1995).

FISHERIES

Fisheries enterprises can be divided into two major elements: (1) commercial and sport fishing; and (2) government agencies, such as the National Marine Fisheries Service, that monitor and regulate fish stocks. These two segments of fisheries have similar technology needs both in terms of environmental data and modeling as well as remote sensing.

Successful commercial and sport fishing operations and accurate fish population assessment and monitoring efforts depend on adequate information on sea surface temperature, surface current patterns, and the depth of the thermocline. These parameters make it possible to estimate the location of fronts which are biologically active and may harbor significant populations of plankton and fish. Although information of this type is not technology, the Navy has data pertinent to fisheries interests, which could be transferred to the commercial sector through various forecasting and data distribution services.

Remote imaging techniques are important in locating and assessing fish stocks, an important component of fish stock management and development. The National Marine Fisheries Service is pursuing the use of lidar (light detecting and ranging) as a tool to track fish stocks, especially open-ocean stocks such as tuna and salmon. Smaller fish that swim and feed in schools could also be monitored with such a system (Borstad et al., 1992). Although much of the existing technology for remote imaging was originally developed for DOD use, it is beginning to be declassified and has great potential as an assessment tool (Hunter and Churnside, 1995).

Areas of ONR-supported research with direct application to fisheries interests lie mostly within ONR 32 and NRL 7000. Imaging techniques developed in these two divisions are beginning to be used for marine forecasting, and enthusiasm is building in the community for airborne assessment of fish stocks by these methods. Meteorologic and oceanographic data and modeling will be of interest to fisheries forecasting services.

ENVIRONMENTAL COMPANIES

The ocean and coastal environmental industry needs science and technology in two major areas: (1) passive and active observation systems (e.g., remote and *in situ*), and (2) predictive modeling. The primary need for these capabilities is in regional seas, bays, sounds, estuaries, and other coastal water bodies. Integrated systems for observation and modeling of coastal and nearshore waters would be of direct and immediate use in assessing the impact of accidental and planned discharges, site evaluation for nearshore and offshore structures, oil and gas exploration and development, disposal of wastes at sea, and routing of ships. At a larger scale, there is a primary need for cost-effective systems for ocean ship routing, studies of air-sea interaction and its influence on climate change, and analysis of environmental variability.

ONR has historically supported, and continues to sponsor, a wide range of hardware, software, and systems that might be a direct match to industry needs. These activities include the design and development of oceanographic instrumentation (e.g., acoustic ocean networks and modems, profiling current meters) needed to measure physical, chemical, and biological parameters. They also include the development and operation of systems for real-time global, regional, and local predictive modeling capabilities.

MARINE EQUIPMENT AND SERVICE PROVIDERS

Marine equipment and service providers can be divided into large multinational corporations and small, independent companies. Suppliers of marine equipment are typically small businesses focused on a single product. Performance and price are important in the competitive market. Products sold by the industry include the following:

- Manned vehicles
- Remotely operated vehicles (ROVs) and bottom crawlers
- Side scan, imaging, and bottom sounding sonars
- Underwater cameras
- Sensors of temperature, pressure, conductivity, water density, currents, and wave height
- Doppler sonar
- Water samplers
- Flow meters
- Data and voice communications equipment
- Underwater position tracking devices
- Connectors
- Cable, pipes, and buoys
- Ships
- Winches, tow bodies, and tow arrays
- Transponders, transducers, and magnetometers
- Valves
- Pressure test enclosures
- Strip recorders, power amplifiers, and data loggers
- Diving systems

Service providers in the marine industry are involved in a variety of activities, including:

- Inspection and mapping
- Marine engineering
- Leasing, cleaning, and installation of equipment
- Data measurement
- Ship maintenance
- Weather forecasting and ship routing
- Seismic surveying

Service companies, in particular, range in size from large global operators to small independent operations. The larger operators are typically associated with offshore oil and gas activities. Many service providers have a large capital investment in equipment and want to maximize the return on that investment. They are reluctant to buy new equipment unless there is a need that cannot be satisfied any other way.

The technology needs of these industries are driven by (1) increasing work depths, (2) more stringent inspection requirements, (3) new environmental monitoring requirements, and (4) the need for increased operating efficiency (i.e., greater submerged endurance, better sensor resolution, increased operating speed, and an ability to operate in a wider range of sea conditions).

FUTURE AREAS OF RESEARCH

The majority of the marine industrial sector faces challenges similar to those of the offshore oil and gas industry, fisheries, environmental companies, and equipment and service providers. Ocean science research and technology development that lead to reduced environmental impact of offshore activities, increased efficiency in the workplace, and improved data collection, assimilation, and dissemination would be of value to a wide range of nonmilitary marine users. ONR is a leader in the development of marine technology and could play an important role in providing technology that would produce such benefits. Research and technology development sponsored by ONR could be applied to a broad range of marine industry needs besides the four areas mentioned earlier in this chapter.

For example, an important emerging need in the marine industry, both for the near-term and increasingly for the long-term, is the ability to operate systems remotely at water depths to 3,000 m, for extended periods in a cost-effective manner. Undersea power sources with greater energy and power densities are a major component of these operating systems. The need for remotely operated systems will grow with the increasing depths and costs of oil exploration; its development will greatly affect work vehicles used at depth and the vehicles used to monitor and survey pipelines. ONR 33 directs some of its research toward increasing the energy density of undersea power systems. Increased emphasis on technology transfer in this area could provide large benefits to the commercial sector.

Additional areas of future research with wide applicability outside the Navy may include (1) physics of seismic and acoustic energy interaction with seafloor topography and subsea floor; (2) analysis and modeling of atmospheric processes at a variety of spatial and temporal scales; (3) enhanced systems for shipboard environmental monitoring; (4) improved satellite image analysis; (5) improved modeling of a variety of oceanic processes (e.g., contaminant transport, air-sea interaction); (6) enhanced techniques for waste disposal; (7) corrosion- and biofouling-resistant materials; and (8) improved marine construction designs and techniques.

5

Approaches to Enhance ONR Technology Transfer in Ocean Science and Technology

To achieve satisfactory levels of technology transfer, four approaches should be considered: (1) contact, two-way communication, and interactive participation between the developer and the potential user of the technology; (2) a new organizational mechanism for technology transfer; (3) incentives for implementing technology transfer, in both the developer community and the user community; and (4) metrics for evaluating the success of the effort. Discussion of these options, while not meant to be exhaustive, is included to provide suggestions for enhancing technology transfer efforts at ONR.

CONTACT, COMMUNICATION, AND PARTICIPATION WITH THE USER COMMUNITY

ONR has historically relied on informal procedures to transfer technology to academic and commercial markets. This has normally been accomplished by participation of ONR-supported scientists in professional meetings and forums. Given the diffuse nature of the ocean science and engineering community, this process, although effective at a small scale, is not necessarily efficient. ONR could considerably strengthen this vehicle for technology transfer by sponsoring special sessions on alternative uses of technology at future professional meetings. ONR might also sponsor special forums where technology transfer opportunities are identified and described in detail. These forums could be held in conjunction with ocean technology meetings (e.g., Offshore Technology Conference, meetings sponsored by the Marine Technology Society and/or Institute of Electrical and Electronic Engineers) and ONR-supported scientists should be encouraged to participate.

ONR could foster technology transfer by active participation in the evolving number of centers and collaborative organizations in the United States. The National Science Foundation, for example, has a well-developed program that brings individuals from academia, government laboratories, and private industry together to establish closer working relationships and transfer technology. These R&D Centers have been formed around disciplinary topics (e.g., instrumentation, data analysis, manufacturing, advanced materials) and also with broad topic coverage (e.g., Ocean Technology Center at the University of Rhode Island).

In marine research and business development, as in other areas of modern society, electronic communications networks have become a common tool to enhance access to people, products, services, data, and information. An important goal of providing this access is efficient transfer of knowledge. To ensure adequate transfer, organizations measure performance of the electronic access system against customer (user) satisfaction and take steps to improve that performance.

ONR has made great strides in making much of the information about ONR programs and contact relationships readily available on the Internet. An example is the "ONR Home Page" on FEDIX (Federal Information Exchange). ONR has three major databases — one for each of the three areas of federally funded R&D: 6.1 (basic and applied research), 6.2 (exploratory development), and 6.3 (advanced development). The data, however, are presented in a compartmentalized, topical directory (i.e., the databases are not interactive with each other). Electronic access to each database currently requires unique knowledge and skills, creating a barrier to effective use. Such obscurity serves the interests of ONR security but impedes effective transfer of technology and knowledge.

Creating a coherent, user-friendly system of data transmission (with appropriate security measures) should be the prime objective of any ONR technology outreach program. Such a system should have not only listings but also a browse capability and a help function. Customers who are unsophisticated with computer systems should still be able to interact productively with ONR's technology program. The discussion here applies not only to contacting the Office of Research and Technology Application (ORTA) and developing Cooperative Research and Development Agreements (CRDAs), for example, but to accessing geophysical data products such as sea surface temperature and ocean circulation models.

A process should be put in place that not only measures the number of successful inquiries to the database but also provides a measure of customer satisfaction. Where matters of legitimate data security exist, the declassification systems for academic access should be extended to the private sector (subject to the same qualifications such protection imposes on academia).

A POTENTIAL NEW ORGANIZATIONAL MECHANISM

A private corporation, financed either (1) under an Advanced Research Projects Agency (ARPA) cooperative agreement in the form of a grant or loan, or (2) directly from ONR, could provide a timely and cost-effective interchange of technology and knowledge between ONR and private-sector companies and venture capitalists. In this report, such a company will be referred to as a Technology Transfer Corporation (TTC). The TTC is presented only as an example of the type of potential innovative solution ONR may wish to consider in an effort to increase technology transfer.

Principles of Operation

- Cost sharing between ARPA and TTC could be arranged such that ARPA provides half the working capital in the form of a grant and half in a loan subject to repayment. The loan portion might be a non-interest-bearing, three-year loan, unsecured, with the possibility of early repayment without penalty. Repayment would be from TTC operational profit after taxes or by allocation of values inherent in equity deals (see below) or royalty income streams, or both.
- TTC gross income would arise from nominal service fees and participation in joint ventures distribution and royalty income. Some type of sliding-scale service fee, perhaps proportionate to the capital of the inquiring party and based on cost plus 10 percent, would encourage serious inquiry.
- The engine of any such enterprise is a system of incentives that encourage the creation of something new from the existing "raw material" represented by ONR technology and private-sector need.

Incentive Structure

- **ONR.** Successful implementation of a new organizational mechanism such as TTC would require active participation by ONR. There are several incentives for ONR participation:

  1. Increased license and royalty fees (per Public Law 99-502, Appendix C)
  2. Equity and dividend participation in third-party joint ventures
  3. Fees for increased use of ONR facilities
  4. Restoration to ONR of $1.8 million in budgeted funds resulting from selective transfer of responsibilities now performed in ONR 31, ONR 32, ONR 33, and ONR 36 (David Rossi, ONR, personal communication, 1995)
  5. Active exchange of knowledge and technology with partners in the private sector. Principal investigators (PIs) and ONR project manag-

ers should be an integral part of technology transfer accomplished through a TTC or any other mechanism.

- **ARPA.** Incentives for ARPA to participate include effective performance of its mandated mission, broadened reach into currently inaccessible areas of the private sector, and the possibility that the 50 percent grant will be recovered in the form of cash or value repayment.
- **Private sector.** Incentives for private sector companies and venture capitalists would include the profit potential. Venture capitalists could be included among prospective ONR partners in the formation of start-up enterprises to capitalize on yet ill-defined applications of ONR technology in the private sector.
- **TTC.** Standard entrepreneurial profit would exist as an incentive for any potential TTC. Start-up capital would be only half debt; equity would be shared with ONR on joint ventures; profit potential would be tied directly to performance in the transfer of knowledge and technology.
- **Academia.** Both private and public CRDAs and TRPs would be largely outside the exclusivity of the TTC; therefore, the approximately $400 million of current ONR awards to 3,000-4,000 PIs for 6.1 (basic and applied research) projects would be largely unaffected. The same would apply for SBIRs and CRDAs.

The foregoing TTC profile is intended only as an example of the type of innovative program ONR may wish to consider; consequently, details are absent from its description. The creation or implementation of any new organizational mechanism should include the establishment of clear program goals and relevant metrics to ensure that any intermediary entity truly facilitates rather than impedes technology transfer. The suggestion reflects the conviction, however, that the current status of ONR technology transfer cannot be remedied by minor reforms alone. What is needed is a basic, organizational course change. The private sector is the best source of information on what it needs, at what cost, and on what timetable. Creating a TTC is one way for that need to be addressed. ONR should explore various options to promote technology transfer, including changes in organizational structure. In addition, small business should be an important target of ONR technology transfer efforts, as smaller companies have the organizational flexibility for rapid assimilation and use of emerging technology (Berkowitz, 1994).

INCENTIVES

The incentives cited for a TTC are equally applicable to existing ONR technology transfer programs. Other programs should be set up to provide incentives to specific groups to promote technology transfer. Some suggested incentive plans for each major participant in marine research and development are provided below.

ONR Scientists and Engineers—ONR should set aside an inviolate portion of its research funding to focus on the transfer of technology to the nonmilitary sector. Several key technology transfer opportunities could be identified and grants awarded to ONR researchers working in cooperation with a commercial firm to produce a commercial product, process, or service. Cost sharing from the commercial firm might be required as a measure of its commitment and financial capability to transfer the product or service to the marketplace. Such an award system could readily be incorporated into the TTC concept discussed above.

Other incentives in the form of awards or recognition could be used to show the value of technology transfer. These could take the form of financial awards or simple recognition by higher management of successful technology transfer efforts within a research program. Although there exists a policy designed to reward DOD employees for domestic technology transfer (DOD, 1988) and a program to carry out that policy (see Chapter 3), this program appears to be vastly under used. Evidence of successful technology transfer could be made part of the performance evaluation of ONR employees at all levels. This would encourage employees to consider technology transfer as a vital part of their professional responsibilities.

Academic Scientists and Engineers Supported by ONR—ONR sponsors approximately 4,000 basic and applied research projects at an average of about $100,000 per project. The "typical" project includes a PI and a graduate student (or a postdoctoral researcher). While the following suggestions would not appeal to all PIs, some would use it to enhance technology transfer.

If the PI is able to arrange industrial cosponsorship for an ONR-sponsored project, ONR could underwrite the indirect cost for up to $30,000 of the industrially funded direct cost (up to, perhaps, $15,000 for each year of the ONR-sponsored project). This added cost to ONR would enable the cosponsoring industry to "buy into" a highly leveraged project and help ensure that the focus of the research involves the company's commercial needs and product interests.

ONR could also seek an option exercisable at a later stage of the research when the project is more mature or has become more attractive to the potential commercial sponsor, although a lack of early involvement by ONR may hinder later success. The PIs obviously benefit by increasing their research output potential (e.g., an additional graduate student can be supported). The advantage to ONR is essentially the same: increased technology transfer (at the local researcher level) and greater quantity and quality of research (from a commercial standpoint). The students involved benefit by gaining an understanding of both the Navy's scientific interests and the company's (market-driven) interests.

METRICS

Although ONR supports many efforts in technology transfer, it is currently difficult or impossible to determine the effectiveness of the various approaches and programs. A clear set of standards must exist for evaluation of all technology transfer programs, and these metrics should be incorporated into the performance evaluations of key personnel. An effort should be made by the Chief of Naval Research to identify and state what standards will be used.

An interagency working group (including members from the Army, Navy, and Air Force, as well as the National Institutes of Health and the Department of Agriculture) exists, in part, to define technology transfer metrics. This effort is still in progress, and the metrics have not yet been identified. The delineation of clear metrics will be an important step toward adequately measuring the success of technology transfer programs and identifying areas where improvement is necessary.

6

Findings and Recommendations

The success with which the Office of Naval Research (ONR) carries out its mission clearly depends on mastery of the marine environment. This competence comes from a predictive knowledge of ocean processes as well as the tangible technology necessary to operate within the marine regime. With declining federal support to various agencies, it is critical that ONR maintain its leadership in ocean sciences, technology, and education and further focus its efforts in the ocean environment. This role will ensure continued U.S. leadership in marine technology and provide the information and technology pool on which the private sector can draw. The present vertical integration of the agency could provide a structure to facilitate technology transfer. This structure should then be augmented, as discussed in this report, to improve the means and the measurement of technology transfer to military and nonmilitary users. The findings and recommendations discussed below are intended for use by the director of ONR's Ocean, Atmosphere and Space Department and the Chief of Naval Research. These recommendations can and should be acted upon as soon as is practically possible.

ONR RESEARCH AND TECHNOLOGY DEVELOPMENT

Finding: The Office of Naval Research supports leading-edge research and development in many areas of ocean science and technology with applications for nonmilitary users.

ONR-supported research accounts for a tremendous array of leading-edge scientific information and technological developments with potential application to nonmilitary problems. These products range from coatings and materials to reduce ship corrosion at sea to sophisticated computer models for predicting the fate and transport of oil spills (see Chapter 2). The high-quality scientific research and the technology development supported by ONR are an important component of the Navy's efforts to maintain combat readiness and tactical advantage. The committee recognizes that research and development (R&D) supported by ONR is of vital importance to fleet effectiveness and national defense. Many of ONR's marine research programs and the resulting products, as well as the expertise they represent, do not exist in the nonmilitary sector.

Recommendation: ONR should continue to fund and nurture long-range marine research and technology development. These efforts should be coupled with the education and training of scientific and engineering personnel in ocean science and technology.

STATUS OF TECHNOLOGY TRANSFER AT ONR

Finding: Federal agencies are mandated by public law to transfer technology (see Appendix C). The transfer of ocean science and technology within the Navy and to other government agencies, and to a large extent, to academia, appears to be adequate. Technology transfer to the nonmilitary commercial sector, by contrast, is clearly inadequate. This inadequacy is particularly evident in the transfer of technology to major U.S. corporations that lack a history of involvement with ONR and to small companies (less than 100 employees and less than $30 million in revenues) of all types.

The Navy's mission of national security has properly dominated ONR thought and action. The transfer of ONR-sponsored technology and knowledge to the private sector is, however, directed by Public Law 96-480 (Appendix C) and interpreted by DOD Regulation for Domestic Technology Transfer:

> *Make available for use within the Component not less than half of one percent (0.5 percent) of the total R&D budget, to support the domestic technology transfer functions of the Component as specified in Section 11 of Public Law 96-480 (Reference [a]). This provision may be waived by notification to Congress on an annual basis at the same time as the budget submission to the Congress including explanation of reasons for the waiver and alternate methods of conducting the technology transfer function.* Department of Defense (1988, pp. 1-4).

This provision was amended in 1989 by Public Law 101-189 (Appendix C) to require that "each Federal agency which operates or directs one or more Federal laboratories shall make available sufficient funding, either as a separate line item or from the development budget, to support" technology transfer. In response to this directive, ONR has structured and staffed a system incorporating Cooperative Research and Development Agreements (CRDAs), an Office of Research and Technology Applications (ORTAs), and specialized programs for patent license and shipyard and vessel improvement. Although it is unclear whether the funding mandate is being met, the level of activity and results demonstrate that technology transfer is not effective in the ocean science and technology areas.

Representatives of marine industries indicated to the committee that there is little direct involvement by ONR in commercial offshore research and development activity. An examination of the few measures of performance available (e.g., participation by ONR in cooperative research and development agreements, number of patents licensed) seems to support this view (see Chapter 3).

Recommendation: ONR should allocate sufficient resources to ensure the success of technology transfer to the domestic nonmilitary sector in ocean science and technology.

TECHNOLOGY TRANSFER AT ONR: THE ORGANIZATION

Finding: Even though an organizational structure apparently exists to facilitate domestic technology transfer by ONR, the existing process is primarily *ad hoc* and reactive rather than proactive.

Industries that do not have a connection to ONR find it difficult and costly to gain access to information available at ONR. The perception is that there is valuable technology at ONR but that existing mechanisms are not adequate to promote the development of this technology for commercial purposes (see Chapter 3). For these and other reasons, simply introducing financial or personnel management policies may fail to stimulate the technology interchange desired. There is a need for a new organizational mechanism that acknowledges that the private sector is the best judge of what technology it needs, at what cost, and on what timetable (see Chapter 5). ONR does not possess the experience and perspective required to make such determinations without significant input from the user community.

Recommendation: ONR needs to take a more proactive role in domestic technology transfer in ocean science and technology. This can be accomplished using a combination of strategies, including organizational realignment, electronic databases, newsletters, sponsored forums and workshops, professional association meetings, personal communication among principal investigators, and funding incentives within ONR for programs that facilitate commercial product development. The existing programs intended to promote communication between ONR and the nonmilitary sector should be used to determine industry needs.

TECHNOLOGY TRANSFER AT ONR: THE INDIVIDUAL

Finding: Few incentives apparently exist within ONR to promote domestic technology transfer at the level of administrative program managers and investigators.

Investigators both within and outside of the Navy are motivated to produce superior research or develop new technology so they may receive continued funding or peer recognition. Similar inducements do not exist to leverage R&D efforts for application beyond their originally intended use. ONR investigators are well intentioned, but to take further advantage of R&D expenditure, additional incentives are required to encourage the extra effort needed to focus on technology transfer (see Chapter 5). Exploiting (or leveraging) technology must become a performance objective of the entire ONR organization.

It is beyond the purview of this study to recommend specific program goals and levels of performance to ONR. As the principal executive of ONR, however, the Chief of Naval Research should create plans for the transfer of technology with specific objectives and milestones for accomplishment. Such plans should reflect the program wide priority to be placed on technology transfer to the nonmilitary sector. Progress toward achieving these objectives should be managed like any other development project and progress should be reported on a regular basis. Individual performance objectives should be established, beginning with top ONR executives and including all team leaders and laboratory investigators. Individuals should be rewarded or recognized on the basis of achievement measured against these objectives. To ensure the success of technology transfer, effective training will be required to enable all employees to understand both the goals and the mechanisms of effective technology transfer.

Recommendation: Incentives need to be provided at the program level, and measures of performance established at the executive level, to promote domestic technology transfer. The Chief of Naval Research needs to provide executive leadership and operational training at all levels of the organization to implement an effective technology transfer policy.

References

Berkowitz, B.D. 1994. Why defense reinvestment won't work. Technology Review 1:53-60.

Borstad, G.A., D.A. Hill, R.C. Kerr, and B.S. Nakamisha. 1992. Direct digital remote sensing of herring schools. International Journal of Remote Sensing 13(12):2191-2198.

Department of Defense (DOD), Undersecretary of Defense for Acquisition. 1988. Domestic Technology Transfer Program Regulation. DOD Report No. 3200.12-R-4. Washington, D.C.

Hunter, J.R., and J.H. Churnside, eds. 1995. Airborne fishery assessment technology - A NOAA workshop report. SWFSC Administration, La Jolla, Calif.

MEDEA. 1995. Scientific utility of Naval environmental data. A report to the Navy Meteorology and Oceanography Command, McLean, Va.

National Petroleum Council. 1995. Research, development and demonstration needs of the oil and gas industry. National Petroleum Council, Washington, D.C.

National Research Council (NRC). 1991. *Symposium on Tactical Oceanography*. National Academy Press, Washington D.C.

National Research Council (NRC). 1992a. *Oceanography in the Next Decade: Building New Partnerships*. National Academy Press, Washington D.C.

National Research Council (NRC). 1992b. *Symposium on Naval Warfare and Coastal Oceanography*. National Academy Press, Washington, D.C.

National Research Council (NRC). 1993a. *Research Opportunities in Ocean Acoustics*. National Academy Press, Washington, D.C.

National Research Council (NRC). 1993b. *Research Opportunities in Marine Geology and Geophysics for ONR Programs*. National Academy Press, Washington, D.C.

National Research Council (NRC). 1993c. *Research Opportunities in Oceanic Chemistry for ONR Programs*. National Academy Press, Washington, D.C.

National Research Council (NRC). 1993d. *Research Opportunities in Coastal Sciences for ONR Programs*. National Academy Press, Washington, D.C.

National Research Council (NRC). 1993e. *Research Opportunities in Marine Meteorology for ONR Programs*. National Academy Press, Washington, D.C.

National Research Council (NRC). 1994. *Proceedings of the Symposium on Coastal Oceanography and Littoral Warfare*. National Academy Press, Washington, D.C.

Naval Research Advisory Committee (NRAC). 1993. Defense Conversion. Office of the Assistant Secretary of the Navy (Research, Development and Acquisition) Report NRAC 93-1. Washington, D.C.

Slowinski, G. 1992. The human touch in successful strategic alliances. Mergers and Acquisitions 1:44-47.

Appendixes

APPENDIX
A
Letter of Request

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217-5660

IN REPLY REFER TO
Ser 32/033/94
31 Aug 94

RECEIVED
SEP 12 1994

Dr. William Merrell
Texas A&M University
5007 Avenue U
Galveston, TX 77551

Dear Dr. ~~Merrell~~ Bill:

I am writing to request the Ocean Studies Board's (OSB) assistance in identifying science and technology initiatives that respond to Navy, national, and industry needs. As you are aware, the Navy has become increasingly interested in transitioning the results of its research and development to commercial use, and to pursue "dual use" research. I believe that the OSB could be instrumental in helping the Navy because of the board's interactionwith various parts of the Navy in the past and the board's experience in conducting activities that bring Navy personnel and civilians together to discuss issues of mutual interest (e.g., the Tactical Oceanography Symposia).

I would like the OSB to review the status of dual use research in the Office of Naval Research (ONR) laboratories and to advise ONR on the areas in which the Navy has particular competence and ongoing activities, that are also of interest to industry. I would also be interested in involving staff from the Advanced Research Projects Agency and National Institute of Standards and Technology because of their expertise in technology transfer. I believe that the OSB meeting held at the Naval Observatory last year could provide a starting point for your project. I will commit $100,000 for this activity and would like to receive the report of your study by 30 June 1995. Please call me if you would like to discuss the proposed study in greater detail.

Sincerely,

DR. JAMES J. DeCORPO
Director
Ocean, Atmosphere and Space Department

APPENDIX

B

Biographies of Committee Members

Gerald A. Cann chaired the Committee on Alternative Uses of Naval Technology. He is senior adviser to the Executive Office of Raytheon Company. Mr. Cann graduated from New York University in 1953 and served two years in the U.S. Army Signal Corps. He is a former assistant secretary of the Navy (Research, Development, and Acquisition). Mr. Cann has more than 40 years of experience in senior management, including more than 20 years in industry and 20 years in the government specializing in technology application, system development, and acquisition. He has extensive experience in program development, program execution, and reorganization of major business units. He is a member of the Ocean Studies Board.

Mary Altalo is associate vice chancellor of marine science, University of California, San Diego, and deputy director for scientific affairs, Scripps Institution of Oceanography. She earned a Ph.D. from the Johns Hopkins University. Dr. Altalo has held positions at the Chesapeake Bay Institute at Johns Hopkins, the College of Marine Studies at the University of Delaware, Martin Marietta, the Biological Oceanography program at the National Science Foundation, and the Oceanic Biology program at the Office of Naval Research. Dr. Altalo has research interests in phytoplankton bloom formation in nearshore waters and has used acoustic and remote sensing techniques to track bloom formation. She served on the Ocean Studies Board Committee on High-Priority Science to Meet National Coastal Needs and is a former member of the Ocean Studies Board.

William Berry is president of Applied Remote Technology, which directs the development of enabling technologies for undersea vehicle systems. He holds a B.S. in electrical engineering from the University of New Hampshire and an M.A. in public administration from the University of Northern Colorado. He has extensive experience in undersea systems development and production.

Charles Black is president of the Mardela Corporation. He has extensive experience in marine technology and as a marine adviser over a broad range of maritime issues. Mr. Black has served as president of the Mardela Corporation since 1968 and chairman of the Marquest Group, Inc., in Bourne, Massachusetts, since 1983. He has been involved with the design, manufacture, and operation of equipment for deep-ocean search, positioning, and imagery and has conducted pioneering work in oyster and marine gastropod aquaculture. Mr. Black has served on a number of national and international marine advisory panels, including the Indian Ocean Fisheries Commission, the Conference on the Law of the Sea, the Marine Fisheries Advisory Commission of the National Oceanic and Atmospheric Administration, and the National Advisory Committee on the Oceans and Atmosphere.

Anthony Calio is executive vice president of Hughes Information Technology Corporation. He is a former undersecretary of Commerce for Oceans and Atmosphere, and assistant administrator for space application for the National Aeronautics and Space Administration (NASA). He holds a B.A. from the University of Pennsylvania, is a Sloan Fellow from the Graduate School of Business at Stanford University, and holds a D.Sc. from Washington University. Dr. Calio was the recipient of NASA's Exceptional Service medal, Exceptional Scientific Achievement medal, and Distinguished Service medal.

Edward Liszka is associate director of the Applied Research Laboratory (ARL) at Pennsylvania State University. He directs the major technology and development programs performed by ARL, including weapons technology, underwater acoustics, and undersea vehicles. Dr. Liska is a past manager of the Navy's technology efforts for undersea weapons guidance and control and was awarded the Navy's Special Achievements Award. He holds B.S. and M.S. degrees in electrical engineering from Pennsylvania State University and a Ph.D. in applied physics from Catholic University of America.

William Silcox is retired from a vice presidency at Wellstream Corporation and a long career with Chevron Corporation as senior offshore engineer in its Offshore Technology and Planning Staff. Mr. Silcox holds a B.S. from the University of California, Berkeley, and has been a consultant to the National Science Foundation's Deep Sea Drilling Project, the National Petroleum Council Task Group on Arctic Oil and Gas Reserves, and the American Petroleum Institute. He is a former member of the Marine Board of the National Research Council and is a member of the National Academy of Engineering.

Malcolm Spaulding is a professor of ocean engineering at the University of Rhode Island. He earned a B.S. and a Ph.D. in mechanical engineering from the University of Rhode Island. Dr. Spaulding studies numerical modeling of coastal and shelf processes to predict oil spill fates and impact and pollutant transport.

Glenn Stoner is an expert on bioelectrochemistry and marine corrosion control. He holds degrees from the University of Missouri and University of Pennsylvania and is currently professor of materials science and engineering and director of the Center of Electrochemical Sciences and Engineering at the University of Virginia in Charlottesville. Dr. Stoner has taught courses in corrosion throughout the United States, Europe, and the Middle East, and is a consultant with several companies and national laboratories. He holds 12 patents and is the author of 75 publications in electrochemistry and corrosion.

APPENDIX

C

Legislation Related to ONR Technology Transfer

(Source: Technology Innovation, Federal Laboratory Consortium Special Reports Series No. 1, West Publishing Company, St. Paul, Minnesota, August 1994)

The Stevenson-Wydler Technology Innovation Act of 1980 - (Public Law 96-480)

- required federal laboratories to take an active role in technical cooperation
- established Offices of Research and Technology Application (ORTAs) at major federal laboratories
- established the Center for the Utilization of Federal Technology within the National Technical Information Service (NTIS) to aid in the dissemination of information.

The Bayh-Dole Act of 1980 - (Public Law 96-517)

- allowed small businesses and not-for-profit groups to obtain title to inventions developed with government support, to encourage cooperation between the government and private groups in developing technology.

The Small Business Innovation Development Act of 1982 - (Public Law 97-219)

- required agencies to provide special funds for small business research and development (R&D) with applications for defense needs.

The Federal Technology Transfer Act of 1986 - (Public Law 99-512)

- mandated that technology transfer be a responsibility of all federally employed scientists and engineers and be considered as part of federal laboratory employee performance evaluations
- established principle of royalty sharing for federal inventors (15 percent minimum) and set up reward system for other innovators
- chartered the Federal Laboratory Consortium (FLC) for Technology Transfer and provided funding for its operations
- Cooperative Research and Development Agreements (CRDAs) made possible between government labs and private companies, with negotiation of licensing agreements and exchange of personnel, services, and equipment.

Executive Order 12591 of 1987 - (EO 12591)

- emphasized the government's commitment to facilitating access to science and technology.

National Competitiveness Technology Transfer Act of 1989 - (Public Law 101-189; included as Section 3131 of the Department of Defense Authorization Act for FY 1990)

- granted opportunities to government-owned, contractor-operated (GOCO) federal laboratories to enter into CRDAs and other activities with universities and private industry
- provided technology transfer mission for nuclear weapons laboratory
- revised amount of budgetary support for domestic technology transfer

Defense Conversion, Reinvestment and Transition Act of 1992

- provided funding for technology transfer activities
- established Technology Reinvestment Project (TRP), administered by the Advanced Research Projects Agency (ARPA)

Small Business Technology Transfer Act of 1992 - (PL 102-564)

- established Small Business Technology Transfer (STTR) programs, within DOD and other federal agencies. STTRs are similar to Small Business Innovation Research programs.
- required federal agencies to fund cooperative R&D projects with small companies, researchers at universities, federally funded research and development companies, or nonprofit research institutions.

Defense Authorization Acts of 1993 and 1994 - (Public Law 102-484; Public Law 103-160)

- encouraged DOD to transfer technology to small businesses
- streamlined processes for technology transfer

APPENDIX

D

Products of ONR-Supported Marine Research and Development

Tables D1-D8 follow.

TABLE D1 Products of ONR 32 Research in Sensors and Instrumentation

Available	Emerging	Future
multi-line arrays	lidar (light detecting and ranging) sensors	nuclear/biological/chemical monitoring
air deployments of sensors	laser line scan underwater imagery	autonomous/networked components
towed thermistor chains (plug-in)	toroidal volume search sonar	airborne hyperspectral optical scanners
vorticity meters	towed vertically directed source (TVDS)	remotely piloted vehicle packages
turbulence (oceanic and atmospheric)	slotted acoustic sources	microstate telemetry
seafloor shear modulus profiler	polymer acoustic sources	
high-resolution seafloor imagery	SPINNAKER UUV (unmanned undersea vehicle)	
RO/RO (roll on/roll off) aircraft data acquisition system	surf-zone turbulence and sediment devices	
laser *in situ* settling tube	full depth towed gravimeter	
ocean bottom seismometers	superconducting gradiometer	
acoustic doppler current profilers (ADCP)	robust thermal anemometers	
acoustic lance	coherent acoustic doppler for turbulence	
beta @180° meter	focal plane array imaging radar (FOPAIR)	
scanning ocean surface slope gauge	remote (optical) slick detection	
microlayer samplers	aerosol samplers (*in situ* and remote)	
fiber optic tow cables and connectors		
polar ozone aerosol measurement system		
ocean microstructure profilers		
ice stress/deformation devices		
suspended sediment acoustical backscatter sensor (ABSS)		

Source: Office of Naval Research.

TABLE D2 Products of ONR 32 Research, Miscellaneous

Available	Emerging	Future
liquid pulsed power switch	laser eye surgery for myopia	rapid net deployments
electron mobility in liquids	explosive ordinance disposal methods	biology (e.g., fish stock) management by acoustics
	marine mammal tracking and tagging	
	undersea breathing systems	
	multi-gas sensor	

Source: Office of Naval Research.

TABLE D3 Products of ONR 32 Research in Algorithms and Measurement/Analysis Techniques

Available	Emerging	Future
internal wave imaging (acoustic and optical)	ocean color and bottom reflectance	water quality by optics
extremely low frequency/very low frequency/low frequency (ELF/VLF/LF) radio propagation	synthetic aperture sonar (SAS)	underwater object ID by remote optics
ocean stereophoto analysis	under-ice optical transmission	fusion of optical/acoustic signatures
matched field processing	marine radar "sea spikes"	acoustic holography of underwater objects
chirp sonar	SAR polarimetry for wind stress	through-the-sensor data assimilation
seismo-acoustic velocities	Lagrangian tracer processing	stochastic (long-range acoustic) inversions
deterministic tomography	fathometer sediment classification	mine countermeasures by neural nets
synthetic aperture radar (SAR) for surface currents, ice thickness	electromagnetic sediment classification	ultra wideband (UWB) radar "spectroscopy"
tunneling electron microscope (TEM)/environmental cell	cloud retrieval from AVHRR (advanced very high-resolution radiometer)	over-the-horizon radar for ocean surface currents
Lagrangian/Eulerian floats (adaptable)	stochastic (ocean) tomography	acoustic daylight
towed profiling systems	surrogate littoral environment	ionospheric tomography
inverted echo sounder	geomorphology province classification	marine boundary layer tomography
near surface void (air) fraction	acoustic thermometry	real-time, all source survey optimization
flow cytometry on a chip (for *in situ* devices)	bottom tomography, sea ice tomography	convection/subduction tracers
in situ nitrate/nitrite tracers	video plankton recorder	
bottom acoustic loss (for mine countermeasures)	3-D imaging of sediments, particle velocimetry	
towed profiling systems	benthic surface activity scanner	
	high-capacity/low-power data storage	
	biologic distribution by acoustics	
	rainfall and breaking waves by passive acoustics	
	near-surface hydrodynamics via acoustic scanning	

Source: Office of Naval Research.

TABLE D4 Products of ONR 32 Research in Evolution (Process) Models and Simulation

Available	Emerging	Future
optical radiative transfer (e.g., HYDROLIGHT)	Langmuir circulations	fully coupled nearshore wave/current/ bathymetry
hydraulic control of straits	new mixed layer models	assimilating regional models
radiation belt models	frontal dynamics	massively parallel codes
surf-zone wave prediction	aerosol nucleation	on-scene analysis/forecast
internal wave spectra	2-D and 3-D acoustic propogation/ reverberation	coastal meteorology
eddy-resolving (1.4°) basin models	Kalman assimilation and fusion methods	atmosphere-pulsed optical properties
global ocean prediction (1/8°)	radionuclide assessments	embedded training and simulation
coupled operational predictive models	ice rafting, ridging, and leads	virtual product developments
ice/ocean/air prediction	estuarine (dynamic) classification	volume visualization
tropical cyclone motion and structure	marine boundary layer large-eddy simulation codes	
distributed and interactive systems	coastal water clarity simulations	
simulator linking protocols	littoral remote sensing simulations	
	sediment shock wave propogation	
	nearsurface bubble distributions	
	simulator control architectures/protocols (for uniform fidelity)	

Source: Office of Naval Research.

TABLE D5 Products of ONR 32 Research in Ocean/Civil/Coastal Engineering and Research Vessel Designs

Available	Emerging	Future
fish-bite damage assessment (cables)	slack cable dynamics	autonomous ocean sampling networks
novel mooring designs (S-tether)	full-induced vibration models for cable strumming	nonlinear stochastic design
vortex sediment resuspension	expendable moorings	shock mitigation for high-speed boats
imbedded "design wave" stochastic simulations	acoustic lenses	shallow water sub-bottom swath mapping
multiaxial material testing	hand-held sonars	offboard unmanned sensor platforms
inductive modems (moorings)	fish propulsion mechanisms	real-time sensor fusion and model assimilation
nonlinear floodgate models	water jet propulsion (efficiency)	parallel sampling from single ship
wave groupiness effects	high-speed projectile water entry	adaptive remote sampling
undersea membrane models	"wick" combustor power source	low- or self-powered gliders (ocean and atmosphere)
3-D unsteady flow codes	infragravity surf wave models	
lithium-seawater battery	offshore bar migration and beach profile evolution	
harbor/jetty wave attenuation	high-temperature material fracture and constitutive behavior	
destratification due to bubble plumes	ice forces on structures	
remote vehicle designs	airship methods	
floating instrument platform (FLIP)	remotely piloted aircraft (RPAs)	
arctic logistics/methods	arctic submarine	
manned submersibles (ALVIN)	profiler motion compensation	
remotely operated vehicle (ROV) controls	"expendable" mini-winch	
deep-submergence ROVs	profiling CTD	
ROV/AUV tools (e.g., rock drill)		

Source: Office of Naval Research.

TABLE D6 Products of ONR 33 Research in Environmental Protection and Materials and Coatings

Available	Emerging	Future
large and small shipboard solid waste pulper	nontoxic, antifouling coatings	shipboard HAZMAT destruction
solid waste shredder	automated underwater hull maintenance vehicle	shipboard air conditioning systems
oil-water separator	inhibitor of vandate corrosion	shipboard refrigeration systems
paint removal and containment system	paints without volatile organic compounds	new antifouling coatings
shipboard, gray water treatment system	electrochemical spectroscopy for coating evaluation	
shipboard, oily wastewater treatment system		
remote sensing of crevice corrosion		
water-displacing coatings		
microencapsulation for coatings		

Source: Office of Naval Research.

TABLE D7 Products of ONR 34 Research in Biofouling, Biocorrosion and Biosensors, and Marine Mammal Studies

Available	Emerging	Future
duplex coating system, reduces toxic curing zinc optic fiber biosensor diving physiology of marine mammals information on low-frequency sound impacts	nonfouling materials structural materials for sensor array scaffolding biosensors with combination of receptors biomimetic autonomous underwater vehicles biomimetic engineering of sonars, signal processing	algal biotechnology molecular composites sediment biogeochemistry

Source: Office of Naval Research.

TABLE D8 Products of NRL 7000 Research in Acoustics, Remote Sensing, Oceanography, Marine Geosciences, and Marine Meteorology

Available	Emerging	Future
acoustic signal processing	deep-towed acoustic geophysics system	simulation of acoustics
at-sea acoustic sensors for locating objects	fiber-optic strain sensors	modeling and simulation of remote sensing
ocean modeling and prediction	ultraviolet cameras	
advanced techniques for mapping seafloor	biocorrosion research	
probes for pore-water pressure	bioluminescence system	
Polar Ozone Aerosol Measurement system	simulation, visualization, and image analysis techniques	
shipboard systems for data management, processing, display, and dissemination	digital database design and data compression techniques	

Source: Office of Naval Research.

APPENDIX
E

Acronyms and Definitions

ARPA—Advanced Research Projects Agency
AUV—autonomous underwater vehicle, an untethered submersible capable of operating without receiving real-time instructions

CNR—Chief of Naval Research, administrative head of the Office of Naval Research
CRDA or **CRADA**—Cooperative Research and Development Agreement, a cooperative agreement between a federal agency or agencies and any nongovernment party

DOD—Department of Defense
DTT— Domestic Technology Transfer, a program implemented by the Navy and other agencies to manage and monitor the transfer of technology to the nonmilitary sector

FTE —Full-time effort or equivalent, a measure of work or effort considered to be equivalent to one individual working full time

NASA—National Aeronautics and Space Administration
NIST—National Institute for Standards and Technology, a federal agency within the Department of Commerce
NRAC —Naval Research Advisory Commission
NRL—Naval Research Laboratory, an agency within the Office of Naval Research

NRL 7000 - an organizational entity within the Naval Research Laboratory specifically responsible for ocean and atmospheric science and space technology
NTIS - National Technology Information Service

ONR - Office of Naval Research, the primary agency within the Department of the Navy responsible for conducting and sponsoring scientific research and technology development for use by the fleet
ONR 32— Department of Ocean, Atmosphere and Space Science and Technology, organizational entity within the Office of Naval Research responsible for conducting and sponsoring scientific research and technology development for use in the ocean, atmosphere, or space
ONR 321—Sensing and Systems Division, primary program within ONR 32 within which remote sensing research and development is housed
ONR 322—Modeling and Prediction Division, program within ONR 32
ONR 33—Engineering Materials and Physical Science and Technology Department, organizational entity within the Office of Naval Research primarily responsible for developing new materials for use in naval equipment
ONR 34—Personnel Optimization and Biomolecular Science and Technology Department, organizational entity within Office of Naval Research primarily responsible for research and development for systems that interface with the biosphere (e.g., work equipment, coatings to reduce barnacle attachment)
ONR 36—Industrial Programs Department, organizational entity within the Office of Naval Research responsible for research and development in manufacturing science and industry outreach
ORTA—Office of Research and Technology Application, a function established in each DOD activity to coordinate the Domestic Technology Transfer Program as outlined in DOD 3200.12-R-4
OSB—Ocean Studies Board of the National Research Council

PI— principal investigator

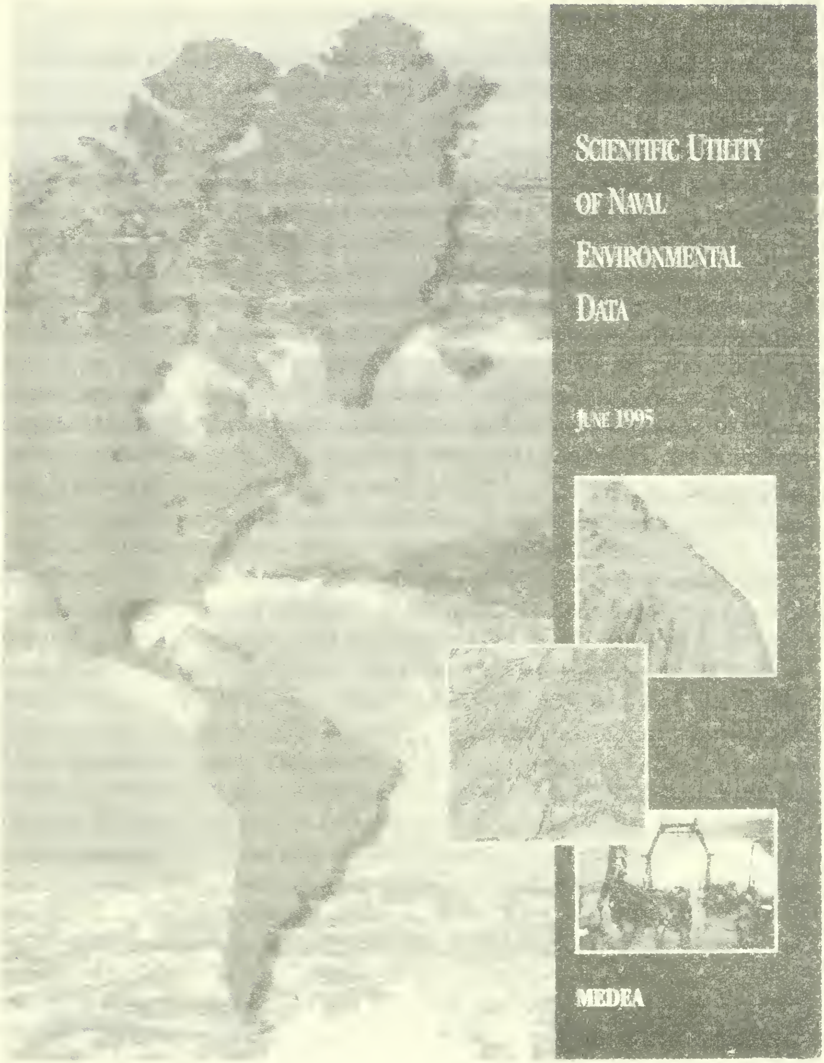
R&D—research and development
ROV—remotely operated vehicle, an undersea vehicle that receives instructions from a surface vessel or manned submersible or similar remote location, commonly over a communications tether or cable

S&T—science and technology
SBIR—Small Business Innovation Research, a program sponsored by federal agencies such as the Navy to facilitate the commercialization of technology by small businesses

TRP—Technology Reinvestment Program, programs that emphasize cost-shar-

ing cooperation between federal agencies and the civilian sector for the development of military technology for nonmilitary use
TTC—Technology Transfer Cooperation, a mechanism specifically suggested in this report as a means to further facilitate the transfer of technology from the Navy to the nonmilitary sector

6.1—basic and applied research, a federal funding category that targets the earliest stages of technology development
6.2—exploratory development, a federal funding category that targets intermediate stages of technology development, in which original concepts are developed for potential operational use (e.g., design of a prototype)
6.3—advanced development, a federal funding category that targets the last stages of technology development before concepts are made fully operational (e.g., construction and testing of a prototype)



SCIENTIFIC UTILITY
OF NAVAL
ENVIRONMENTAL
DATA

JUNE 1995

MEDEA

MEDEA

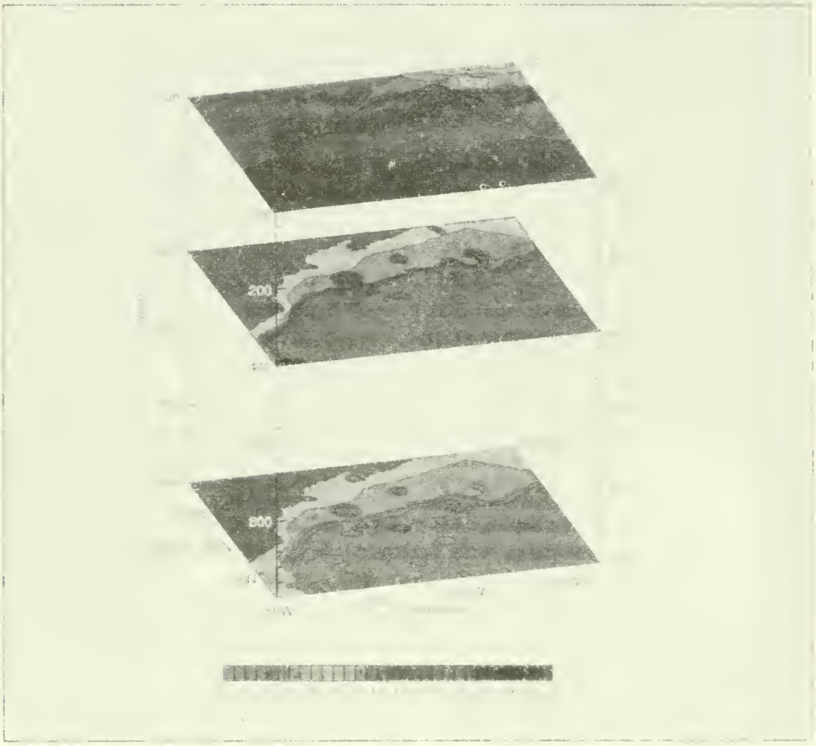
SCIENTIFIC UTILITY OF NAVAL ENVIRONMENTAL DATA

A MEDEA SPECIAL TASK FORCE REPORT

June 1995

MEDEA

Representation of Ocean Thermal Structure in the Western Atlantic



FOREWORD

June 1995

This report from a MEDEA Special Task Force is provided in response to a request from the Navy Meteorology and Oceanography Command to examine its oceanographic data holdings and determine their potential scientific utility. The conclusions reported here represent the result of a remarkable collaboration between civilian scientists and members of the Navy's oceanographic community. The results of this collaboration have led to the identification of numerous databases which, if made available to the civilian community, would greatly advance the ocean sciences and our knowledge of the ocean environment.

We clearly recognize that serving the needs of national security through oceanographic support to naval operations remains the primary responsibility of the Naval Meteorology and Oceanography Command the primary custodian of the data examined in this study. However, because of the resources and time involved, the data collected by the Navy for this purpose are truly unique and could never be duplicated in the civilian sector. Release of these data in an appropriate way would advance the state of ocean science by many years and result in an important public benefit from the Navy's previous investments.

The release of these data would also facilitate a closer working relationship between civilian and Navy ocean science communities, to the benefit of both. It is my firm belief that such collaboration would strengthen the Navy's overall capabilities to understand and utilize the oceans in addressing its national security responsibilities.

It is my hope that the scientific conclusions reported here, when viewed by others in the light of post-cold-war evolution in our national security needs, will lead to appropriate ways to make these important data publicly available.

Gordon J MacDonald

Dr. Gordon J. MacDonald
Chairman, MEDEA

PREFACE

At the request of RADM Paul G. Gaffney, Commander, Navy Meteorology and Oceanography Command (NAVMETOCCOM), an assessment was conducted of the potential scientific utility of the capabilities and classified data holdings of NAVMETOCCOM. The present report describes the results of that assessment as those data and capabilities were observed during the spring of 1995.

The study was performed by a subset of MEDEA scientists representing a broad spectrum of ocean science disciplines. The scientific judgments and conclusions reflected in this report are those of the following individuals:

Dr. Mark R. Abbott	Oregon State University
Dr. Ralph N. Baker	Amoco Production Company
Dr. Otis B. Brown, Chair	University of Miami
Dr. Warren W. Denner	EOS Research Associates
Dr. Walter H. Munk	Scripps Institution of Oceanography
Dr. John A. Orcutt	Scripps Institution of Oceanography
Mr. Albert E. Pressman	Naval Research Laboratory
Dr. Robert A. Shuchman	Environmental Research Institute of Michigan
Dr. Norbert Untersteiner	University of Washington
Dr. John F. Vesecky	University of Michigan
Dr. Wilford F. Weeks	University of Alaska

The coordinator of the study and editor of this volume was Dr. Kenneth E. Hawker, Jr., The MITRE Corporation.

ACKNOWLEDGMENTS

This study was accomplished with the assistance and guidance of both RADM Paul Gaffney, Commander, and Dr. Donald Durham, Technical Director, of the Navy Meteorology and Oceanography Command (NAVMETOCCOM). In addition, the technical support and advice of Landry Bernard and Dr. William Jobst, Naval Oceanographic Office (NAVOCEANO), CAPT Larry Warrenfeltz, Commanding Officer, National Ice Center (NIC), and Dr. Paul Moersdorf, Fleet Numerical Meteorology and Oceanography Center (FNMOC), are greatly appreciated and contributed significantly to this study. Their enthusiastic cooperation and support ensured that the MEDEA Task Force was fully briefed on all of the relevant databases, capabilities, and products.

It would be difficult to overstate the value of the efforts put forth by the many individuals in these organizations who assisted with this study, particularly in the face of the demands of their existing duties and commitments. In this regard, the assistance of NAVOCEANO in providing many of the figures appearing in this report is particularly noted.

In addition, meetings were held with representatives of the Arctic Submarine Laboratory and the Applied Physics Laboratory of the University of Washington, whose contributions greatly improved the treatment of an important topic addressed here.

As with its various predecessor studies, this MEDEA effort was made possible by the foresight, planning, and dedication of Dr. Linda Zall, Central Intelligence Agency (CIA).

A number of individuals associated with MEDEA have contributed ideas and energy to the process and their efforts must be acknowledged. These especially include several MEDEA scientists who were involved intermittently in meetings and discussions, and who provided review comments on this report. In addition, CDR Steve Smolinski, U.S. Navy, and Dr. Murray McDonald, Environmental Research Institute of Michigan (ERIM), were very helpful during the process of defining the study and collecting information, and their efforts are gratefully acknowledged.

The MITRE Corporation provided technical and administrative assistance to the study and produced this report. The dedicated efforts of Philip Rost and Laura Hinton, who were involved with this study from its inception, were particularly instrumental. The efforts of Dennis Violett in producing the many illustrations appearing here, David Przewlocki in production and layout of this report and the security assistance provided by Robbin Bradley are also gratefully noted.

The full and enthusiastic cooperation of all of these individuals and organizations was instrumental to any success that may be achieved and is warmly acknowledged.

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Executive Summary

GENESIS OF THIS MEDEA STUDY

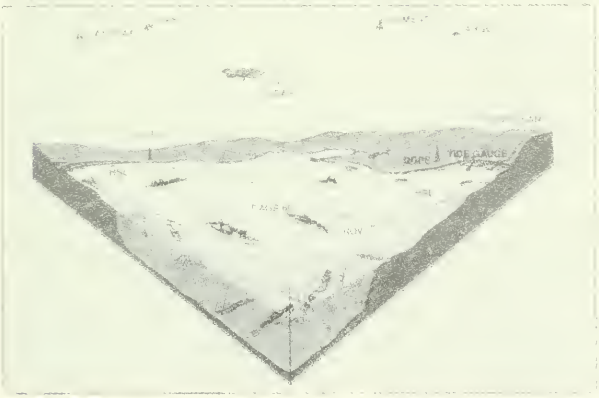
There is a growing public understanding that changes in Earth's environment, both natural and manmade, can significantly affect important dimensions of the nation's vitality, including aspects of the economy, quality of life, international relations, and national security. An enhanced scientific understanding of the key physical processes (such as global transport of heat and carbon dioxide via ocean circulation) is key to developing appropriate and responsive public policies. A major limitation to achieving this understanding is the lack of historical observations and adequate ongoing measurements of these environmental processes. In addition, the interests of U.S. national security are increasingly concerned with ensuring environmental security on global, regional, and national scales. In order to develop public policies based on a quantitative scientific understanding of the environment in the face of limited resources available for new programs, it will be necessary to exploit fully the environmental data resources already collected by the Navy (indeed of all of the Department of Defense [DoD] and the intelligence community) during the course of the cold war.

In response to a request from Vice President (then Senator) Gore, an Environmental Task Force (ETF) was established in 1992 by the Director of Central Intelligence (DCI), including involvement by DoD and other agencies. The primary emphasis of the ETF study was on space-based systems and capabilities, including the National Technical Means (NTM). Some attention was paid to a variety of Navy systems and databases; however, that study did not encompass an in-depth examination of the full variety of the Navy's oceanographic data sets and capabilities.

There was an opportunity to address those omissions with the formation of the MEDEA follow-on to the original ETF. Therefore, at the Navy's request, the present study was undertaken to examine the various classified databases, products, and capabilities of the Naval Meteorology and Oceanography Command (NAVMETOCCOM).

The intention of this study was to determine the potential for unique and important environmental research arising from the use of existing classified Navy databases, and to prioritize these data for subsequent Navy declassification efforts. In addition, this study was to identify opportunities for collaboration between the civilian and Navy ocean science communities that could benefit both, and to suggest ways to obtain increased national benefit from previous public investments in global data collection and modeling by the Navy.

Figure 1 Naval [illegible] Data Collection



Over many years, and with increasing technical sophistication, the Navy has conducted systematic survey and measurement operations covering most of the world's oceans. Over the decades of the cold war, these operations, involving several dedicated ships, amassed results from about 100 ship-years of data collection.

Data collected include measurements of the marine gravitational and magnetic fields, seafloor bathymetry and sediment properties, and such physical properties as salinity and temperature vertical profile sections. Various other naval platforms, such as aircraft and unattended buoys, have been used extensively in this measurement program.

RECOMMENDATIONS

The major product of this study is a set of recommendations encompassing three dimensions:

- An identification of the potential for the Navy's oceanographic databases to support important scientific research, should public release become possible;
- A determination of how scientific benefit, consistent with national priorities in science and technology, can be obtained from those data that national security concerns have thus far prevented from being publicly available; and,
- A specification of means whereby closer ties between the naval and civilian oceanography communities could be achieved that would be a significant benefit to both parties.

Table 1 contains the top-level recommendations of this study. In combination, these recommendations, if adopted, would result in greater exploitation and societal benefit of the considerable public investment in the unique environmental databases and modeling capabilities developed by the Navy during the decades of the cold war. In addition, through improved ties to its basic research underpinnings, the applied science of naval oceanography would be strengthened.

It would be beyond the purview of this study to become enmeshed in issues related to the possible implementation of the recommendations to follow. However, it is very clear that resources will be required, including some level of manpower, perhaps some investment in hardware and software for processing and data exploitation, and, of course, time and funding. Here we can only recognize the need to examine the resource question without quantifying its magnitude.

TABLE 1. TOP-LEVEL RECOMMENDATIONS

- ***Payoff from Declassification***
  The Navy should consider prompt declassification of the high priority environmental data sets identified within this report. The uniqueness of much of the Navy's oceanographic data, the near impossibility of civilian replication, and the high value to scientific research, especially global change, combine to argue that this course is in the broad national interest. If entire data sets are found to be not declassifiable, the Navy should continue to work in an iterative fashion with MEDEA to find ways of releasing subsets of data, possibly through decimating, segmenting, or developing derived products.

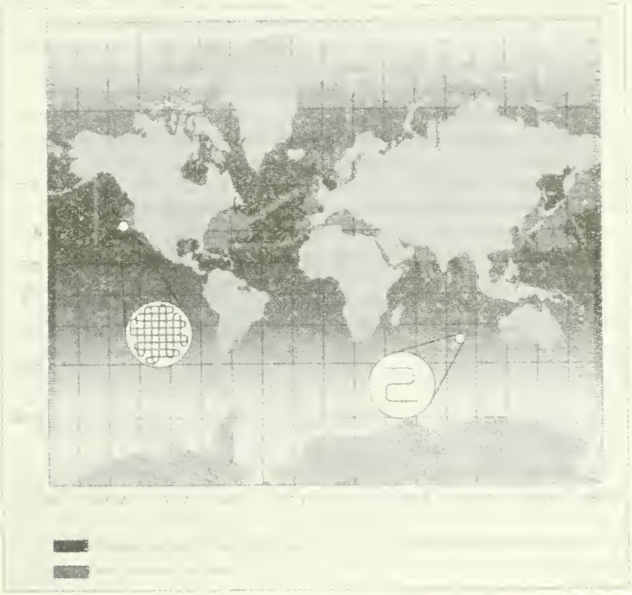
- ***Priorities of Scientific Payoff***
  When reevaluation of classification for these unique holdings is undertaken through a systematic classification review, the priorities recommended here for the scientific value of these environmental data should be explicitly included on the benefit side of the ledger against national security needs (as provided for in Executive Order 12958, Sec. 3, April 1995).

- ***Scientific Exploitation of Classified Oceanographic Data***
  The Navy should consider implementing mechanisms to facilitate broader access to the oceanographic and geophysical data that must yet remain classified. One such mechanism should be an oceanographic data exploitation center located at the Stennis Space Center (SSC).

- ***Scientific Exploitation of NTM Ocean Fiducial Data***
  The National Technical Means (NTM) ocean fiducial observations should be archived at the Stennis Space Center (SSC). Scientific exploitation will require simultaneous use of these observations with correlative oceanographic data currently resident only at the Naval Oceanographic Office (NAVOCEANO). This combination will facilitate prompt exploitation of the NTM data, whereas waiting until the correlative data are available at the central United States government fiducial archive site would postpone effective use of the ocean fiducial data and jeopardize the very rationale for their collection.

- ***The National Interest and Ocean Science***
  It is in the national interest for the United States government to work to improve interactions between the Navy and the broad ocean science community. There are clear and immediate opportunities for "bridge building" between elements of naval oceanography and the civilian ocean science community. Such "bridges" will significantly benefit both parties.

FIGURE 2 [illegible]



The red shaded area illustrates the global scope of the Navy's oceanographic survey and measurement program. As the tapered shading suggests, there has been a greater concentration of resources in the Northern Hemisphere than the Southern Hemisphere.

Also shown schematically are inset illustrations of how different the densities of ship tracks might be in different ocean areas. Tracks of naval oceanographic surveys (blue) from just the unclassified cruises covering the years from 1986 to 1995 show the worldwide nature of the sources of data.

Examination of all survey ship tracks from the entire cold war history of naval survey operations would show both a global breadth of coverage and a scientifically well founded spatial sampling of ocean processes.

SCIENTIFIC UTILITY

Discussion

During the past 30 years, the Navy's ocean surveys have systematically collected bathymetry, gravity, magnetics, and salinity/temperature data on a global basis. In particular, these surveys encompass almost all of the Northern Hemisphere (Figure 2). Altogether more than 100 ship-years of data acquisition have been devoted to this effort, making this the most comprehensive ocean surveying activity ever undertaken. **It is highly unlikely that such an effort will ever be repeated, and it is certain that civilian environmental scientific resources could not aspire to an ocean survey program of this magnitude during the next 20 years.**

The scientific value of this data set and other data examined, such as acoustic ice thickness data collected from submarine upward-looking sonars (ULS), is extraordinary. The unclassified release of these data would almost certainly result in significant advances in many fields of ocean and geophysical science. Release of currently classified data and improved access to classified data by researchers would stimulate the civil/academic scientific community to produce new knowledge and data products that would, in turn, be useful to the Navy. Such a process would be highly cost-effective, gaining leverage from the large public investment already made by the Navy in collecting the data sets.

A past example of scientific benefit from the declassification of oceanographic data involved Geosat. Geosat Altimetry data south of 30° S were declassified, which resulted in a significant advance in our understanding of the tectonics of the southern ocean and the identification of previously unknown seamounts. (Results from a limited analysis of these data have been published by scientists having access to the classified data.) Another historical example, though remote from oceanography, involves data from the VELA satellites, originally flown to detect atmospheric nuclear tests. Events having considerable astrophysical significance today, gamma ray bursts, were first observed and then monitored by these satellites for some six years prior to their declassification in the 1970s. On a larger scale, the entire civilian, space-based remote sensing program owes its origins to earlier successes and technology of the classified satellite reconnaissance programs. We can expect that interesting, but unexplained features in the Arabian Sea, observable in synthetic aperture radar (SAR) imagery at the NASA Space Radar Laboratory, should be interpretable using much needed ground truth data, such as the temperature and salinity data in NAVOCEANO's ocean thermal and salinity-profile databases.

The major specific findings of this study, supporting the top-level recommendations, are divided into two categories: (1) identification and prioritization of the scientific utility of the various data sets examined, and (2) developing ways to improve the community's capabilities in ocean science.

Through a series of briefings and discussions, we were exposed to a great many of the Navy's environmental data sets and capabilities, and we have identified a subset of significant importance. Furthermore, to support the Navy declassification review that we expect to follow, the data sets have been prioritized in two categories of "potential importance." The prioritization reflects our view of the uniqueness of the data, and it represents the potential for important results to be obtained, if public release were possible.

Findings

The major findings related to various specific data sets that were examined are summarized in Table 2.

No attempt was made to evaluate the national security implications of possible public release of these data sets, this being a topic outside our purview. That is, we have accounted for *neither* any possible impact on national security from potential public release, *nor* of how favorably the Navy might view the release of any particular data set. Further, no cost has been attached to any possible future effort to declassify, bundle, or reformat data or create automated access by cleared scientists in as much as we understand that the existence of such costs do not constitute legitimate grounds for continued classification.

We recognize that, even in the face of a judicious weighing of national security risks on the one hand, and public benefits of declassification on the other, declassification of entire data sets may, in some cases, prove to be imprudent. In such cases, it may very well be possible to declassify geographic subsets of the

Table 2. Findings Related to Specific Data Sets

- ***Scientific Utility***

  We have singled out 10 data sets whose potential for supporting important science is so significant that our first recommendation to the Navy is to "...consider prompt declassification of the high priority environmental data sets identified here." Four of these data sets are in the domain of geology and geophysics (Marine Gravity, Geomagnetics, Geosat Altimetry, and Seafloor Sediment Properties), two are concerned with sea ice (Ice Keel Depth Acoustic Data and Historical Ice Morphology), and four are concerned with the volume and boundary properties of the ocean (Marine Bathymetry, Realtime Salinity and Temperature Fields [GOODS], Archival Salinity and Temperature Fields [MOODS], and Ocean Optics and Bioluminescence).

- ***Prioritization of Data Sets***

  The listing below shows a twofold prioritization of the probable scientific importance and uniqueness of the data, should they be made publicly available.

First Tier	*Second Tier*
• Marine Gravity	• Historical Ice Morphology
• Geomagnetics	• Seafloor Sediment Properties
• Ice Keel Depth Acoustic Data	• Realtime Salinity and Temperature Fields (GOODS)
• Marine Bathymetry	• Archival Salinity and Temperature Fields (MOODS)
• Geosat Altimetry	• Ocean Optics and Bioluminescence

data, decimated or smoothed data, or in particularly sensitive instances, only derived products. This report does not attempt to give guidance bearing directly on the details of such a compromise position on declassification, nor do the priorities in Table 2 account for this dimension. Therefore, in anticipation of the Navy eventually facing the necessity to understand declassification payoffs vs. national security risks, it is our view that **a declassification review of these environmental data should include MEDEA involvement (in a scientific advisory capacity) in order that the necessary compromises elicit the most scientifically useful data.**

IMPROVING CAPABILITIES IN OCEAN SCIENCE

Discussion

The Navy has developed truly unique capabilities to synthesize oceanographic products from diverse and heterogeneous data and to display the results in useful graphical forms. Beyond the more traditional forms of product generation involving large-scale ocean thermal, salinity, and density fields, this synthesis now includes the development of small-scale regional models in selected ocean areas of naval interest and the exploitation of imagery, including classified NTM imagery. This product synthesis capability, if it were opened to civilian use, could lead to an expanded national benefit. There has been a considerable investment of public funds in these capabilities, and scientific access would pave the way for ocean science to move more rapidly into small-scale oceanography.

The intelligence community, with congressional support, has established a program to collect and archive classified NTM imagery data collected from a set of reference sites that will be regularly surveyed over time periods ranging from years to decades. Currently, in excess of 200 sites are being considered for data collection. This Global Fiducial Data Program is intended to archive data to be used in scientific studies of the global environment, albeit requiring classified access. Some of these measurement sites are ocean areas, and one important result of the present MEDEA study has been the realization that scientific exploitation of the ocean fiducial data must involve analytical use of correlative NAVOCEANO oceanographic data. These "correlative data" are in many cases the same as that discussed in Chapter II: ocean thermal and salinity structure, high-resolution bathymetry, etc. The proper scientific exploitation of the ocean fiducial data is, therefore, closely tied to ensuring access to NAVOCEANO's databases and modeling capabilities.

On the other hand, there are few regular and effective mechanisms for the flow of information to naval oceanography from academia. It is our conviction that such a flow of information, involving modest collections of irregularly sampled "shoe box" measurements or recent progress in dynamic ocean models, for example, would be of considerable benefit to naval oceanography and to the accuracy of fleet products.

Several institutional mechanisms would have to be put in place to facilitate access to classified information if scientists are to realize full benefits from the environmental data holdings of the national security community. The establishment of a consistent, long-term environmental record of digital data could benefit from the participation of cleared members of the environmental science community in the collection requirements process (as is being done in the Global Fiducial Data Program).

The environmental science community might also participate in the development of policies to ensure that archival products are of maximum utility to the environmental community. For example, these policies could provide guidance to the national security community as to which data to index, abstract, declassify, and transmit outside their facilities. Environmental scientists could also benefit from the establishment of processes and systems for requesting data and transforming material for distribution. Finally, the development of new concepts of operations that support the complementary use of classified and civilian sensors could also be investigated. These could include processes to implement sensor cross-cueing, develop composite products, and perform calibration and validation.

FINDINGS

The bridge building path with institutional mechanisms and links between the civilian and Navy oceanography communities has many of the same features as the road toward scientific exploitation of oceanographic data that must yet remain classified. The findings covering these dimensions are summarized in Table 3.

Table 3. Findings Related to Improving Ocean Science Capabilities

- ***Exploitation Center***

  An exploitation center, installed at the Stennis Space Center, supported by a high-data-rate local area network would allow access to essentially all NAVOCEANO databases, models, and product synthesis capabilities by appropriately cleared and United States government-sponsored civilian scientists, thus facilitating scientific use of these data and generating feedback to the Navy.

- ***NTM Global Fiducial Data***

  This exploitation center should also be the repository for the National Technical Means (NTM) ocean fiducial data, thus offering both access to oceanographic capabilities for their intrinsic value and facilitating scientific exploitation of the NTM data.

- ***Regional Model Fields***

  Building on Navy interest in littoral ocean areas, the Navy should expand its current efforts to build regional ocean models to include areas in proximity to the United States, possibly beginning with the Gulf of Mexico, which includes nearly all littoral types. The relatively dense observations available in the Gulf area would help develop and validate regional models.

- ***Access to NAVOCEANO Capabilities***

  Facilitating the civilian use of databases and models through permitting access to the Integrated Database Management System (IDBMS) being developed by NAVOCEANO would be a significant positive step. Remote access to the classified version of IDBMS, with local exploitation through the exploitation center or via an encrypted link, should be arranged. On-line connectivity should be provided to databases approved for public release, thus vastly accelerating civilian use and generating feedback to the Navy.

- ***Interagency Collaboration***

  The entire oceanography community, Navy and civilian alike, would greatly benefit from a much stronger partnership among the United States government ocean science agencies: the Navy's Office of Naval Research (ONR), National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), Department of Energy (DoE), and the National Science Foundation (NSF).

- ***Visiting Scientist Positions***

  Provision should be made for one or more visiting senior scientist positions at NAVOCEANO and civilian scientific participation in ocean surveys.

I. Introduction

A. PURPOSE

The primary purpose of this study is to examine the various classified ocean databases, products, and capabilities of the Naval Meteorology and Oceanography Command (NAVMETOCCOM) and determine their potential value for supporting civilian scientific research, should public release become possible. In addition, the study is to determine if there might be important opportunities for synergistic collaboration between civilian and military ocean technical communities that could benefit both parties and so derive increased benefit from the considerable public investment in global ocean data collection and modeling previously undertaken by the Navy.

Although aside from the primary purposes of this study, we understand that the Navy also values this review because it is a comprehensive and independent look by outside experts at the quality of Navy data and data management processes. On this point, feedback was provided informally to the Navy during the actual process of the study. We were greatly impressed not only with the unique environmental data sets, but also with the general scientific quality of the work and the processes of data collection, analysis, and product generation.

B. GENESIS OF THIS MEDEA STUDY

There is a growing public understanding that changes in our physical and biological environment, both natural and manmade, can significantly affect the national economy, our quality of life, and even the national security. For example, natural disasters (*e.g.*, earthquakes, volcanoes, floods, hurricanes, forest fires) can cause substantial loss of life and material damage, changes in climate can adversely affect our environment (*e.g.*, global sea levels, agricultural fertility, habitats of endangered species), and environmental pollution can degrade the vitality of populations and ecosystems. To deal with the potential effects of environmental change, an enhanced scientific understanding of the key processes is needed. A major limitation to achieving this understanding is the lack of historical environmental observations and continuing scientific measurements of these processes. In recognition of this need, in 1992 Vice President (then Senator) Gore called for the creation of a panel of cleared environmental scientists who would evaluate assets of the national security community that could help resolve critical environmental issues. In response to this request, an Environmental Task Force (ETF) was established by the Director of Central Intelligence (DCI) and endorsed and participated in by the Departments of Defense (DoD), Commerce (DoC), Interior (DoI), and Energy (DoE), and, as well as by NASA and other agencies.

Throughout 1993, the ETF scientists were briefed on a wide variety of classified systems and data/archives from many segments of the national security community to allow them to assess the applicability of these resources to environmental concerns. A final report was then issued by the ETF containing an assessment of the potential scientific utility of the classified data should public release later become possible. The ETF also dealt with other opportunities for gaining scientific payoff from these data and capabilities, including introducing the concept of derived products (primarily graphical) in order to facilitate declassification of limited specific information.

The concept of global "fiducial" data collection by classified sensor systems in support of scientific research and environmental monitoring was also introduced. The regular sampling of a preselected set of fiducial sites was seen as complementary to data collected by civilian sensors and would be a means of beginning a long-term archive of well-sampled data on a set of scientifically significant sites.

While the primary emphasis in the 1993 ETF final report involved space based systems, including the National Technical Means, some attention was also paid to a variety of Navy systems and databases. This included brief mention of databases such as high resolution bathymetry, submarine acoustic ice keel drafts, and Geosat altimetry, as well as a substantial look at the Integrated Undersea Surveillance Systems. However, constraints of time and U.S. government priority prevented an in-depth examination of the full range of oceanographic, polar ice, and meteorological databases and capabilities which were developed by the Navy during the decades of the cold war.

Subsequently, with the formation of MEDEA, there was an opportunity to rectify these omissions. MEDEA consists of a group of about 50 cleared scientists drawn from academia, government, and industry. Disciplines and interest areas include geology and geophysics, oceanography, atmospheric science, polar science, urban growth, land cover and land use, climatology, remote sensing, environmental remediation, and others. There is considerable commonalty in MEDEA with the original ETF group. MEDEA has been sponsored by the intelligence community, with direct involvement of the DoD and the Services, in particular from the offices of the Oceanographer of the Navy and the Commander, Naval Meteorology and Oceanography Command.

The present study was undertaken by a subset of MEDEA as a logical extension of the original ETF work as a result of a request from Naval Meteorology and Oceanography Command. The intention was to determine the unique potential of these data for important use in scientific research, if public release of currently classified oceanographic data were to become possible. This study was also to identify opportunities for collaboration between the civilian ocean science and Navy communities that could benefit both. In addition, it was to suggest ways to obtain increased national payoff from previous public investments in global data collection and modeling made by the Navy. Finally, the intention was to determine if there were means whereby limited scientific benefit of currently classified data could be obtained in cases where public release would not yet be possible (*i.e.*, "derived products").

C. NAVAL OCEANOGRAPHY BACKGROUND

In the 1800s during the early days of the Depot of Charts and Instruments, the objective of Navy oceanography was to provide mariners with the information they needed for safe and efficient navigation. Since World War I, when submarines came into widespread use, submarine and anti-submarine warfare have evolved rapidly to the point where today both have a deep and fundamental reliance on exploiting detailed physical properties of the oceans. Once sonar became a valuable tool to submarines and surface ships during World War II, its effective use required another dimension in understanding of the ocean environment, namely acoustical oceanography. With the advent of naval aviation, and particularly with aircraft operating off carriers, came the need for accurate maritime weather forecasts.

Evolution of computer and communications technology, along with advances in meteorology and global weather data collection, allowed forecasts of many environmental parameters to be made and transmitted to naval units operating around the world. Thus, ship and aircraft routing became important parts of the NAVMETOCCOM's mission. More recently, the long ranges of modern weapons systems, and their precise targeting requirements, forced global predictions of synoptic physical parameters from the depths of the ocean to outer levels of the atmosphere with standards of precision not previously achievable.

The NAVMETOCCOM consists of the Naval Oceanographic Office (NAVOCEANO), Fleet Numerical Meteorology and Oceanography Center (FNMOC), several Fleet Support Centers, and numerous operational units around the world. This worldwide organization comprises about 3,000 officer, enlisted, and civilian personnel; two master computer centers; a number of theater centers; and the ships and aircraft used in conducting oceanographic surveys.

FIGURE 3. OCEANOGRAPHIC SURVEY CHALLENGES

The scale of the Navy's ocean survey and measurement program has been immense. This has been the result of its global mission responsibilities, and of the priorities given during the cold war to anti-submarine warfare (ASW) and other Navy operations requiring technical support in oceanography and meteorology.

Dedicated ship services have collected data in all seasons across the breadth of the Northern Hemisphere as well as over much of the Southern Hemisphere.

The Command's mission is to collect, interpret, and apply global environmental data and information for safety at sea and for weapons system design, development, and deployment. The Command also provides meteorological, oceanographic, mapping, charting, and geodetic surveys to U.S. military forces for use in operational missions. Three major components of this command are described below:

- The Naval Oceanographic Office (NAVOCEANO) is the largest single element of the Command and one of its two master computer centers. Its primary mission is to conduct oceanographic multidisciplinary surveys of the world's oceans. The office collects hydrographic, magnetic, geodetic, chemical, navigation. and acoustic data using ships, aircraft, spacecraft, and other platforms.

- The Fleet Numerical Meteorology and Oceanography Center (FNMOC) operates the other master computer center, and produces global- and regional-scale meteorological and oceanographic prediction products, including analyses, forecasts, and tactical decision aids. These products are tailored for direct operational use by Navy ships and aircraft.

- The National Ice Center (NIC), formerly known as the Navy/NOAA Joint Ice Center, has as its primary mission providing realtime, quantitative operational support concerning the state of the polar oceans, and in particular the ice covers of these oceans, to agencies of the U.S. government. Although NIC does not provide direct project support to non-governmental organizations, its primary unclassified product, the bi-weekly global sea ice assessments, are available to the general public via computer files.

The components of this Command have been an integral part of the development of meteorology, oceanography, and other areas of geophysics in the U.S. The earliest part of the organization was the Depot of Charts and Instruments (1860), under Matthew Fontaine Maury, and the Naval Aerological Service (1919). From 1842 to 1861 the organization was referred to as the Observatory and Naval Hydrographic Office. Later this office became the Naval Hydrographic Office (1866), responsible for charting and maintaining other vital data in support of the Navy's needs. The Naval Oceanographic Office was established in 1962 and was moved in 1978 from Washington, D.C., to the Stennis Space Center (SSC), Bay St. Louis, Mississippi, where it resides today. Also located at the SSC is its parent command, the Naval Meteorology and Oceanography Command that reports to the Chief of Naval Operations (CNO) through the Oceanographer of the Navy.

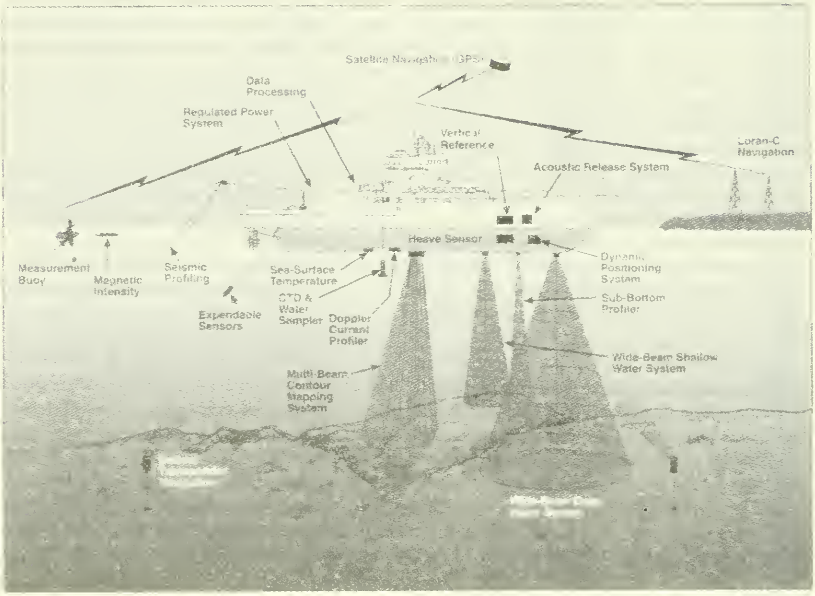
The Naval Aerological Service became the Naval Weather Service in 1956. The Weather Bureau-Navy-Air Force Joint Meteorological Weather Prediction Unit was activated in Suitland, Maryland, in 1954, and moved to Monterey, California, in 1959 to become the Naval Weather Service's Fleet Numerical Weather Central. Its first operational computer center appeared in 1961. It was renamed the Fleet Numerical Meteorology and Oceanography Center in 1993.

Today, the end result of an immense revolution in technology combined with a growing understanding of ocean physics over the past 100 years and changes in the conduct of naval warfare is a Navy increasingly reliant on exploiting detailed physical and acoustical data on the Earth's oceans. Consequently, the Navy has invested in global ocean surveys and other large-scale measurement programs, as well as supported the development of sophisticated predictive models.

During the decades of the cold war, and continuing today with a shift in emphasis toward shallower, littoral waters rather than deep waters, the U.S. Navy has come to be the world's leader in global ocean data and ocean-modeling capabilities. A particularly telling and relevant indicator of the magnitude of the U.S. Navy's investment in oceanography are the at-sea surveys encompassing magnetic, gravity, and bathymetric surveys involving about 100 ship-years of data collection.

There is no other dimension of the global environment where so much of our current scientific understanding and so many of the fundamental measurements have been rooted in the efforts of one of the military services. It is clear from the outset then that the resources the Navy has devoted to oceanography and ocean surveys have resulted in unique, extensive, and detailed databases with no civilian counterpart. As we will see in this report, this expectation was indeed realized over the course of the study.

FIGURE 4. NAVAL OCEAN SURVEY SHIP CAPABILITIES



This illustration of NAVOCEANO's newest class of survey ships, TAGS-60, shows many of the measurement capabilities necessary to collect the types of environmental data examined in this study.

The depths of the open ocean can only be sampled satisfactorily with specialized survey ships capable of operating in heavy seas, handling heavy equipment, and providing extensive equipment spaces and berthing facilities for large scientific parties.

NAVOCEANO has routinely employed dedicated ships having a variety of deep ocean survey equipment. Historically there have been four to six of these ships operating at any given time.

D. IMPLICATIONS OF SECURITY CLASSIFICATION

The integrity and success of scientific research depend in a fundamental way on the scientific method and the peer review process. Central to these is the concept of independent reproducibility and testability of research results, and these in turn require open public access to all relevant data and information. While it is true that various scientific journals do differ somewhat in their degree of tolerance for omitted experimental details, there is no doubt that the standard in scientific research is that the bulk of material must be open to all.

Fundamental scientific insights on controversial subjects, global warming for example, will itself generate significant pressure for declassification. The scientific community at large is self-regulating through the use of refereed publications where experimental details and results need to be candidly displayed under the light of a constant peer review process. On topics subject to controversy, less than open discussion is, at best, counter productive and usually leads to acrimony and confusion.

We understand that, despite the ending of the cold war and the emergence of a new national security paradigm, there remain legitimate needs for the continued protection through classification of some dimensions of the Navy's ocean data. It is essential, though, to be clear about what can and cannot be done, if classification policies remain as they stand today. A significant change in these policies may be necessary, if we are to realize the full scientific promise across the breadth of ocean and Earth sciences foreseen here.

The Executive Order (EO) that provides the basic legal authority for national security classification within the defense and intelligence communities has recently been extensively revised. EO 12958 of April 20, 1995, signed by President Clinton, with an effective date of October 14, 1995, replaces its predecessor EO 12356. While this new EO introduces significant changes to many dimensions of security classification, for present purposes it is only important to note that it **specifically authorizes balancing of the public interest in order to declassify information that continues to meet the standards for classification.** It also requires both automatic declassification of information at least 25 years old (with very narrowly drawn exceptions) and calls for both systematic and mandatory declassification reviews.

In addition, we understand that there are efforts in progress within the DoD concerning the declassification of several of the databases examined by this study. At a minimum these include

- An effort directed by the Office of the Secretary of Defense (OSD) to develop a response to the recommendations made by the ETF, including naval dimensions that partially overlap with those of the present study;

- Discussions within the OSD and the Services concerning the advisability of declassifying Geosat data and making available precision Global Positioning System (GPS) capabilities;

- Efforts by the Oceanographer of the Navy and the Commander, Naval Meteorology and Oceanography Command to declassify selected data such as high-resolution bathymetry;

- New classification guidelines have been developed that may result in declassifying some of the submarine acoustic ice keel draft data to be discussed here.

The dynamics created by these and other efforts, with the heated debates that the subject of declassification always provokes, cannot be resolved, or even understood, in a brief study such as this (nor would it be appropriate for us to attempt this). We have, therefore, chosen to set aside consideration of all of these declassification efforts and concentrate solely on identifying the scientific utility of the various data. If one or more declassification efforts result in release of any data set identified here, it will constitute a significant step forward toward achieving greater public benefit from previous investments and is to be applauded.

We believe that, with one exception, there has been no post-cold-war security classification assessment that has taken into account scientific payoff to the national interest on the benefit side of the ledger. The single exception was the Classification Review Task Force (CRTF) undertaken by the DCI and the Secretary of Defense (SECDEF) regarding the classification policies of space-based imagery. The CRTF built its case for the "benefits of declassification" on the ETF study. It is our hope that an assessment comparable to the CRTF will be undertaken of the Navy's oceanography databases, and that the open-mindedness of that assessment will be taken as a model.

We recognize that, even with a careful weighing of national security risks on the one hand, and public benefits on the other, it may prove to be imprudent to declassify some entire data sets. In seeking a compromise position then, it may be possible to declassify geographic subsets of the data (*e.g.*, a set of predefined "postage stamps") or some form of decimated or smoothed data. A second alternative to a perhaps unattainable, complete declassification of entire data sets would be the development of a set of specific derived products. If this were done with a view toward both national security sensitivities and scientific utility, these derived products might balance the "equities" in a mutually agreeable fashion.

It is our view that the Navy should conduct a systematic high-level declassification review of the environmental data considered here. Moreover, this review should include some form of MEDEA involvement. We assume that this would be in an advisory capacity only and would serve to ensure that the necessary compromises proceed so as to elicit the most scientifically useful data.

If, despite searching for compromises to release subsets of data, or derived products, the most important data still cannot be released in unclassified form, some value can yet be obtained by providing classified data access by cleared environmental scientists. Using these data, scientists might then conduct experiments from which scientific insights and products could be derived that shed light on key environmental processes. These experiments would serve to clarify the unique complementary contribution that these data can make to environmental science and to influence the strategy governing the creation of long-term archives.

E. STUDY APPROACH

1. OCEAN SCIENCE CONTEXT

For most missions, civilian and military alike, and for scientific research, the processes of observing and monitoring the oceans involve phenomena having two characteristics in common. First, the interesting problems usually involve large areas and long time periods. Second, many of the phenomena are often difficult to observe with remote sensing (*i.e.*, space-based) systems because of the lack of consistently detectable or "good" observables. Many of the ocean phenomena of interest to both civilian and military communities can be measured only with *in situ* sensors because of the need to sample at depth (*e.g.*, salinity and temperature profiles, water quality, and bathymetry). As a result of the necessary reliance on *in situ* sensors for many types of measurement, and the necessary use of ships and aircraft, the costs of ocean measurement programs, to say nothing of a well-sampled global data set, are very high and increasingly unaffordable.

As a result, oceanography and marine geophysics have always been data-starved disciplines, primarily because of the difficulty and expense of making measurements having the requisite spatial granularity over large ocean areas and for long periods of time sufficient to detect the important trends. This difficulty in dealing with the spatial and temporal granularity of the ocean processes over vast areas is one which frequently leads to either undersampling or to the high costs of well-sampled, ship-based *in situ* measurement programs. To the extent that the relevant phenomena have observables amenable to space-based observation this situation has improved dramatically in the last two decades. A few of many examples include large-scale sea surface temperature, the long wavelength gravity field, and soon with the SeaWiFS satellite, ocean color (related to phytoplankton densities).

We can expect that much of unique value that might be offered to scientific research by naval ocean databases and modeling capabilities would arise because of their unusual spatial and/or temporal coverage relative to their civilian counterparts. We will see that while the classified world has generally the same sensor types as the civilian, the global coverage and, in some cases, the extended time periods over which classified data were taken are their unique distinguishing characteristics.

2. PROCESS

This study was conducted by a group of 11 MEDEA scientists drawn from the oceans, polar ice, geology and geophysics, and atmospheric sciences, augmented by technical and administrative support. Several organizations in the U.S. government, including the Central Intelligence Agency and the Navy, have had the opportunity to review drafts of this report and comment on its technical accuracy, thereby improving the result. However, the judgments reflected in the findings reported here solely reflect the thinking and opinions of the MEDEA Navy Study Group.

The NAVMETOCCOM was instrumental in ensuring that the study group was briefed on all of the relevant databases, capabilities, and products and, moreover, provided most of the figures included in this report. These briefings offered a comprehensive and insightful window into naval meteorology and oceanography. The study group benefited from detailed meetings with NAVOCEANO, NIC, and FNMOC, along with extensive discussions with the Commander and staff of Naval Meteorology and Oceanography Command, and interactions with the Office of the Oceanographer of the Navy. In addition, we met with representatives of the Arctic Submarine Laboratory and the Applied Physics Laboratory of the University of Washington. The full and enthusiastic cooperation of all of these organizations with this study was instrumental to any success that may be achieved and is greatly appreciated.

II. Scientific Utility of Specific Data

A. OVERVIEW

This chapter will assess the potential for important scientific applications of the various data sets and capabilities described to us by the Navy. The Navy data that were reviewed, evaluated, and found to be the most promising are identified in Table 4. We have tried to include enough detail relating to each data set to support a reasoned judgment of individual importance. Each section in this chapter deals with one data set: (1) data description, (2) accessibility, (3) potential scientific utility, and (4) a summary of our findings.

Additional consideration was given to

- Generalized Digital Environmental Model (GDEM)
- Arctic Buoy Program
- Comprehensive Environmental Assessment System (CEAS)
- Acoustic Data and Acoustic Sensing of the Ocean

and a discussion of each of these is contained in Section E of this chapter.

Release of the Navy's classified oceanographic data will lead to the greatest scientific rewards if environmental scientists have access to the original measurements, as with normal scientific practice. However, the Navy has processed many of these data into many different and very useful forms, for example, compiling measured data into ocean provinces or gridded databases that essentially constitute a form of derived product. Many of these "derived forms" have potential scientific utility nearly as great as the original data. A good example of such an instance concerns bathymetry. While it is possible to envision scientific applications that would require the original data (i.e., acoustic soundings from a multibeam profiler) we conclude that a derived product (the gridded databases developed by the Navy) will generally be the most widely useful form and will be the basis of our finding related to bathymetry.

Since all 10 of the data sets listed in Table 4 are restricted or classified, in whole or in part, we have described our understanding of the "accessibility" of each data type. Use of some data is restricted because of the process used to obtain it, or because the data were obtained through an international bilateral agreement. Other data are classified because they have more direct ties to U.S. Navy forces and their operations.

This MEDEA study has only tried to clarify how these Navy data sets, obtained for use by operational forces, might be used for scientific purposes. We did not try to make any judgment about data classification, and we are not attempting to assess the utility of these data for their originally intended purposes—support of Navy operations.

Table 4. Categorization of Data Sets Examined

GEOLOGY AND GEOPHYSICS	SEA ICE	OCEAN VOLUME AND BOUNDARY PROPERTIES
Marine Gravity	Historical Ice Morphology	Realtime Salinity and Temperature Fields (GOODS)
Geomagnetics	Ice Keel Depth Acoustic Data	Archival Salinity and Temperature Fields (MOODS)
Geosat Altimetry		Ocean Optics and Bioluminescence
Seafloor Sediment Properties		Marine Bathymetry

B. GEOLOGY AND GEOPHYSICS

1. MARINE GRAVITY

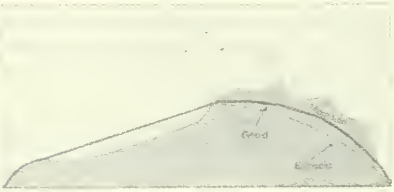
a. Data Description

Gravity is the force that attracts bodies to Earth.[1] In fact the acceleration of gravity over the surface of the Earth is not a constant from location to location. Rotation flattens the Earth's shape near the poles to approximately that of an oblate spheroid, thus reducing surface gravity at the equator. Over the past 30 years, as the need for precision in the positioning and navigation of space vehicles and other platforms increased, it became increasingly important to account for the slightest gravity variations. Thus, not only the general overall shape of the Earth (oblate spheroid) was needed to drive the gravity field, but ever smaller topographic features and geographic structures (which can cause gravity changes sufficient to affect critical instrumentation) had to be mapped.

The Earth's shape has been measured with increasing accuracy ever since the development of earth-orbiting artificial satellites. In the 1980s the Navy measured the equipotential surface of the oceans, the *geoid*, very accurately using a satellite altimeter aboard Geosat (Section II.B.3). The geoid differs significantly from the reference ellipsoid. Not surprisingly, it is possible to derive the gravity field from the geoid; in particular, the product of the gravity field and the geoid anomaly in meters (*i.e.*, the difference between the geoid and the reference ellipsoid) is equal to the anomaly in the gravitational potential. The Navy's accurate measurement of the geoid thus allows a global inference of the associated gravity field.

In dedicated Navy surveys, gravity measurements were made at sea with oceanographic ships tracing closely spaced tracks sufficient to provide scientific quality measurements. Lacoste and Romberg Air-Sea Meters were used from 1966 to 1983, and in 1969 Bell Aerospace BGM-3 and BGM-5 gravimeters were introduced. In addition to collecting the data, scientists measured gravity variations and conducted vertical deflection studies (the difference between the vertical, as indicated by the plumb line of the instrument, and the theoretical perpendicular to the Earth) to obtain true positions. This concept is illustrated in Figure 5. They also computed gravity anomalies (the difference between observed and theoretical values) that can help geologists locate mineral and oil deposits and can be applied to geophysical studies of the Earth.

FIGURE 5. GRAVITY VARIATIONS AND VERTICAL



The geoid differs significantly from the reference ellipsoid. Not surprisingly, it is possible to derive the Earth's gravity field from a precise knowledge of the geoid.

Depicted schematically here are the reference ellipsoid and the perturbed shape of the geoid due to the masses of oceans and mountains. As shown, the different shapes of these two surfaces result in the normal directions being different.

The product of the gravity field and the geoid anomaly in meters (i.e., the difference between the geoid and the reference ellipsoid) is equal to the anomaly in the gravitational potential.

Survey data are digitized at one minute (of time) intervals and indexed by geographic position. These digitized data are called "point data." Representing gravity at one minute (of position) intervals in a survey area is considered the best estimate of gravity at an indexed point. These computed data are called "point-average gravity anomalies." NAVOCEANO collects gravity data in support of required fleet activities, which are usually classified. Figure 6 depicts an example of high-resolution gravity data from the Gulf of Mexico.[2] A study of the data in the Gulf of Mexico provided an opportunity to construct an unclassified one minute point-average gridded data set which is illustrative of the classified data covering much of the world's oceans.

From these at-sea measurements the point observations of gravity were processed and organized into a relational database. This Navy Point Gravity Database consists of a table of marine

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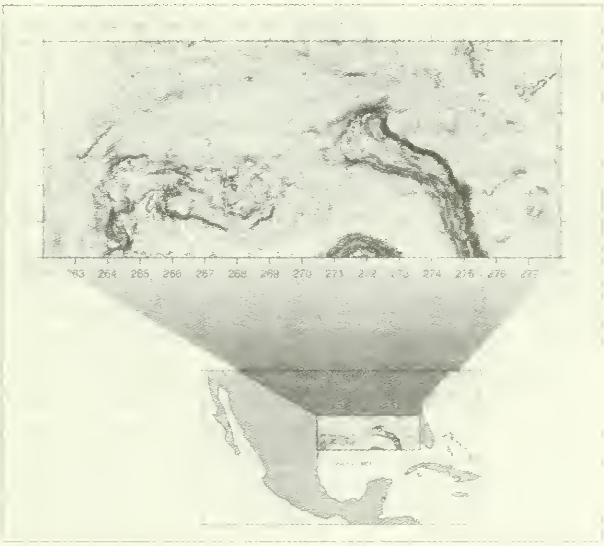
[1] The gravity field results in an acceleration near the surface of ≈9.81 m/s² so that a mass of 1 kg weighs one Newton (N). A gravitational unit, the gal, was named in honor of Galileo, who first systematically measured the acceleration of gravity (gal = 10^{-2} m/s²).

[2] The gravity data shown in Figure 6 as extending over land were taken from an earlier land-based survey and integrated with the NAVOCEANO shipboard measurements to form a single field.

FIGURE 6. FREE AIR GRAVITY CONTOUR DATA IN THE GULF OF MEXICO



This figure shows a contour plot of the gravity field of a section of the Gulf of Mexico at a resolution of one arc minute.

The area shown includes in the right a section of the thickly sedimented Mississippi fan, and in the left center the broken area of the Sigsbee Escarpment (both viewed through the "lens" of the gravity field).

The gridded data used for constructing this plot over water were derived from measurements along ship tracks spaced to sample the gravity high properly.

The entire Gulf of Mexico survey required 34,638 miles of ship track and produced 162,836 original data points. Considerable processing was necessary to ensure data uniformity and to eliminate errors, and then to produce a uniformly sampled gridded data set.

Gravity data over the land area were acquired from other sources.

gravity point observations with the latitude, longitude, observation time, free air anomaly, and gravity value, supported with over a dozen tables containing survey, data processing, and statistical information. The observations table consists of over 38 x 10^6 rows of data which can be sorted by cruise and date-time group or geographic coordinates.

Information is retrieved from the database by both interactive and batch processing. There are Navy plans to replace this database with a relational database and then load the data into the Integrated Database Management System (Section III.C) as the Gravity Core Database.

b. Accessibility

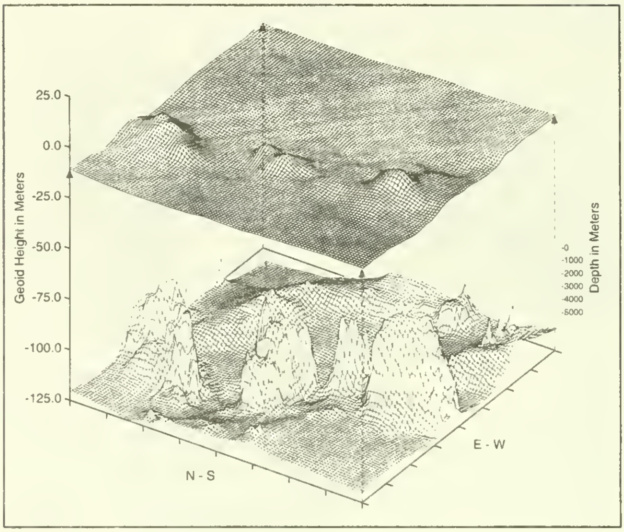
The Navy's ship board gravity data are normally classified because they reveal locations and dates of the ship tracks that might inadvertently release information about operational interests.

c. Scientific Utility

In the presence of a seamount the enhanced gravitational attraction of the seamount will cause the water overhead to pile up above the seamount, resulting in an anomaly in the geoid. A satellite altimeter can thus be used to map the seafloor from space in the same way a shipborne gravimeter can be used to construct a map of the underlying topography (Figure 7).

Unfortunately, the actual situation is not quite as simple as the foregoing would make it seem. Since late last century it has been known that mountains often have light "roots" that allow the mountain to be buoyed up in the fluid mantle in much the same way as an iceberg's keel supports the portion of the body rising above water (Archimedes' Principle). Viewed from far away, the dense mountain is compensated by the light root and the overall gravity anomaly is zero. Because a gravimeter on the ocean's surface is relatively close to the seamount, the

FIGURE 7. RELATIONSHIP BETWEEN GEOID AND SEAFLOOR TOPOGRAPHY



With satellites, the ocean surface's relative heights can be measured. The sea surface height has been shown to correlate with subsurface bottom structure.

This figure shows two very different data sets depicting different views of a small section of ocean.

At the bottom is a high-resolution shipboard measurement of bathymetry, with depths in meters, showing several prominent seamounts. Above this is the geoid of the same area, clearly showing manifestations of the same seamounts on Earth's gravity field. This effect is illustrated schematically in Figure 5.

gravitational attraction, which varies as the inverse square of the distance, is greater than the compensating attraction of the root, which lies deeper in the mantle, and a positive anomaly will be recorded.

This problem is further complicated by the strength of the lithosphere that overlies a more fluid mantle. When a small seamount is constructed by volcanism atop the lithosphere, the seamount is supported largely by the strength of the rigid lithosphere, and Archimedes' Principle never comes into play. The anomaly associated with such a seamount is quite large. However, as the seamount grows in size (or the lithosphere's strength decreases because of heating, for example), the seamount and surrounding lithosphere must obey Archimedes' Principle. Thus, the relationship between seafloor topography and gravity (or the geoid) becomes (spatial) wavelength dependent. Thus, the inference of gravity from topography or vice versa becomes ambiguous in the absence of other information. For example, as the seafloor ages and becomes sedimented and flat, it becomes impossible to infer gravity from seafloor bathymetry. In addition, the spatial relationships between topography and gravity near a volcanic ridge crest, where the lithosphere is very thin, are quite different than the corresponding relationship on more mature, thicker lithosphere.

We have identified three research topics where accessibility of the Navy's currently classified gravity data would lead to important scientific research.

i) Spatial Variations in Gravity at Mid-Ocean Ridges

Recently gravity data have been exploited in a bid to understand basic geophysical processes at mid-ocean ridges. Morphologically, mid-ocean ridges can be broken into at least two fundamentally different classes corresponding to fast-spreading and slow-spreading environments. Slow-spreading ridges are generally characterized by rugged topography and a spreading center bounded by steep mountains. Fast-spreading ridges, on the other hand, are recognized by muted topography and the absence of significant flanking mountain ranges. Detailed geophysical surveys at several locations have been used to propose that mantle upwelling, responsible for delivering melt to the seafloor, is focused at discrete points or plumes at slow-spreading ridges. Mantle flow at fast-spreading ridges, on the other hand, is often associated with proposed two-dimensional or *sheet* upwelling in the mantle. While gravity data inferred from Geosat and ERS-1 data have been used to address this problem in broad brush, sufficiently high-resolution data covering a large extent of the mid-ocean ridge simply have not been available. The release of the Navy's gravity data would greatly facilitate this fundamental research into the genesis of the bulk of the Earth's surface.

ii) Mapping of Crustal Thickness

The composition of the oceanic crust and its density variation with depth are remarkably constant throughout the oceans. Given this generally simple behavior and the significant differential in density between the crust and underlying mantle, gravity data can be used to infer the thickness of the crust and, hence, the depth of the mantle throughout the oceans. While allowing for the eventuality that variations in crustal density do occur, a detailed gravity data set can be used to discover regions of major variations in crustal thickness. For example, the availability of Geosat data south of 30° S clearly outlined an anomalous region of oceanic lithosphere south of Australia which is now called the Australia-Antarctic Discordance. The availability of more detailed gravity data throughout the Northern Hemisphere would provide an unprecedented opportunity for understanding variations in crustal thickness or variations in density that might masquerade as variations in thickness.

iii) The Structure of Fracture Zones

Transform faults are found at mid-ocean ridges where older and young lithosphere slide past each other and are frequently accompanied by earthquakes. The disrupted topography is known as a "fracture zone." The bottom topography and the differential in age across fracture zones in these regions lead to the introduction of loading effects and consequent flexure of the lithosphere. Gravity data collected across such fracture zones and parallel to the original direction of mid-ocean ridges provide important information on the long-term evolution and strength of the lithosphere. Again, the data sets currently available for studying this phenomenon are quite limited. The gravity data would provide the data needed for detailed studies of these processes in the Northern Hemisphere.

d. Findings

The findings relative to marine gravity are:

- **The release of the Navy's high-resolution gravity data would greatly facilitate fundamental research into the genesis of the bulk of Earth's surface because of their unparalleled coverage, detail, and accuracy.**

- **Availability of detailed gravity data throughout the Northern Hemisphere would provide an opportunity for understanding variations in crustal thickness or variations in density that masquerade as variations in thickness.**

- **These gravity data would also provide the information needed for detailed studies of lithosphere processes in the Northern Hemisphere.**

2. GEOMAGNETICS

a. Data Description

Geomagnetics is the science that deals with Earth's magnetism. Magnetic data that can be used to depict the geomagnetic field for any time and location can be used to improve the navigational safety of ships and aircraft of all nations. Because Earth's magnetic field is constantly changing, knowledge of magnetic compass corrections essential to steer a true course are necessary for safe navigation. Early sailors made these corrections by comparing the compass with the direction of the North Star. Today, ships and aircraft are guided by magnetic charts and improved geomagnetic data supplied by NAVOCEANO.

In addition, and for our purposes more importantly, geomagnetic data can be used in scientific studies of the evolution of the Earth's crust. The Earth's magnetic field results from flow in the planet's molten, iron core. The surface manifestation of this magnetic field is a dipole field with both a North and a South (magnetic) Pole. Furthermore, these poles have been, during much of the Earth's history, closely aligned with the spin axis of the planet; *i.e.*, the geographic North and South Poles. For geologists and geophysicists the magnetic field is interesting because the North and South magnetic poles have reversed themselves aperiodically throughout Earth's history; furthermore, rocks cooling from a molten to a solid state can record this ancient field. By mapping small anomalies in Earth's field, therefore, it is possible, by knowing the reversal history, to determine the age at which the rocks were formed through volcanic activity.

The Earth's magnetism is a vector field defined by both a magnitude and a direction. Neither the magnitude nor the direction of this field at a point remains constant in time. The Sun's solar wind causes daily, small variations in the geomagnetic field, and the field measured on the surface varies slowly over time, a phenomenon related to core flow and called "secular variation." This variation amounts to a few degrees in the position of the magnetic poles over the course of a century. Thus, the variation between the magnetic and geographic poles had to be mapped periodically in order to correct magnetic compass headings for true North. Because the magnetic field is horizontal at the magnetic equator and vertical at the poles, the angle of the field with respect to horizontal can be used to determine latitude. Historically this was particularly helpful when neither the stars nor Sun could be used because of weather conditions—a particular problem in the past two centuries for Arctic exploration.

Every few years the geomagnetic field at the surface is published in the current International Geomagnetic Reference Field (IGRF). **For the past two centuries, the U.S. Navy has been a major contributor to these important data. This historic contribution will come to an end this year.** While the advent of the Global Positioning System (GPS) has certainly lessened reliance on magnetic compasses for navigation, they have not yet been eliminated completely. Even apart from the important scientific applications of geomagnetism to be discussed below, we are, therefore, concerned that funding constraints associated with post-cold-war defense downsizing and changing mission priorities may not allow the Navy to continue this valuable public service.

At sea a magnetometer is towed sufficiently far behind a ship to avoid perturbations associated with the magnetic hull. The magnetometer measures the total field of the Earth approximately every 30 seconds.[3] When the IGRF is subtracted from the total field measured, the resultant anomalies (about 1% of the total field) reveal information about the past reversals of the field as recorded in the seafloor rocks. This information led to the geophysical discovery of seafloor spreading and the development of the theory of plate tectonics. In general, the Navy's holdings of shipboard magnetics data, largely in the Northern Hemisphere, is the most coherent, systematic, and complete of any survey ever conducted and, as such, is very important in understanding the past 200 million years of Earth history.

Figure 8 shows an example of a small section of Earth's magnetic field at relatively high resolution. The data shown in Figure 8 were measured by the Navy's Project Magnet aircraft in 1983 at an altitude of 500 feet and have an north/south track spacing of 3 nm with an along-track sampling of 0.25 nm. The magnetic data shown here depict the local field, with both the global field generated by Earth's core and the regional gradient field having been removed. The stripes on the seafloor represent reversals in the Earth's magnetic field and can be used to outline the detailed tectonic history of oceanic crust.

Although these data are from the wholly unclassified aircraft surveys of Project Magnet, they serve to illustrate the spatial complexity of such data and to suggest the quantity of geophysical information that is contained in the higher resolution classified NAVOCEANO ship surveys.

NAVOCEANO's magnetic data are currently stored in simple digital files without software to access or manipulate the data. However these data will be incorporated into the IDBMS before the end of FY 95. This database management system should provide better data accessibility for analyses. There is no existing gridded magnetics database, and constructing one would be a large effort because of the difficulty in reconciling the temporal and spatial variations. There is a plan to acquire scalar magnetic data from the Defense Meteorological Satellite Program (DMSP) S-15 satellite. These data could be used in conjunction with ship-measured scalar data to produce regional magnetic models.

b. Accessibility

Most NAVOCEANO aircraft and satellite magnetics data are in vector form and are unclassified, publicly releasable, and have been turned over to National Geophysical Data Center (NGDC) for public distribution. Virtually all of the ship-

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[3] The strength of magnetic fields are today measured in SI units as Tesla (T), which is kg/amp/s^2. The Earth's magnetic field at the poles is on the order of 6 x 10^{-6} Teslas or 6 x 10^4 nanoteslas (nT). A previous measure, used prior to the adoption of SI units, is the gamma, which is equal to a nT.

FIGURE 8. MAGNETIC FIELD OF THE NORTHERN JUAN DE FUCA AND EXPLORER PLATES

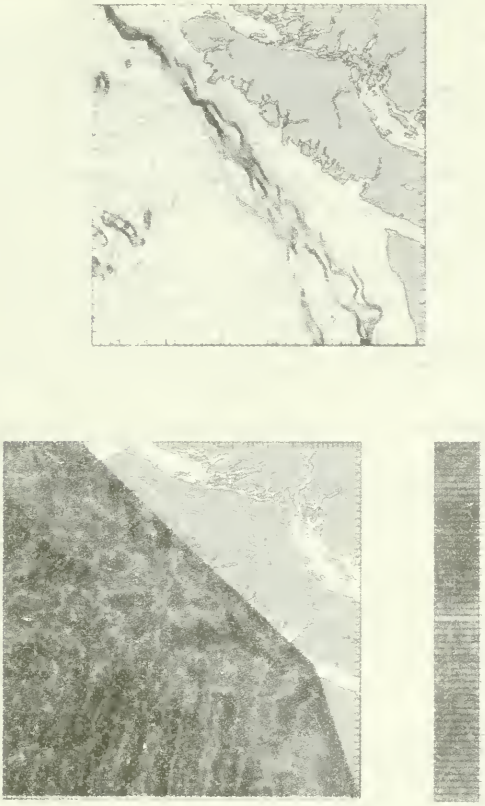


Illustration (bottom) shows the vertical component of magnetic field in the geologically complex Juan de Fuca area of the northeast Pacific (west of Seattle). The ocean area shown contains segments of both the Juan de Fuca and Explorer Tectonic Plates.

These data, from unclassified Navy aircraft surveys, illustrate the general appearance and spatial variability of high-resolution shipboard magnetic data

The more intuitive quantity, bathymetry, is depicted (top) for reference, showing in the lower left, the northeast section of the Juan de Fuca Ridge and the north-west-southeast oriented continental slope.

collected geomagnetic data are scalar data that are classified. Because the scalar data are linked to locations and track lines, formal review is required to determine declassification policy, and very few of these data have been released.

As a result of post-cold-war changes in Navy mission priorities, the Magnetics Program will not be supported beyond FY 95 based on present fiscal plans of the Oceanographer of the Navy. To complete existing work, the Navy will finish production of the epoch 1995 World Magnetic Model (WMM), which was designed to meet DoD needs until the year 2000. Project MAGNET flights (500 hours per year) and the DoD Geomagnetic Library are funded through FY 95. However, the Navy plans to terminate its entire geomagnetic project by FY 96.

MEDEA is particularly concerned that magnetics data may be especially vulnerable to loss, and we feel it is essential that these data be protected. The collected geophysical data have many scientific purposes. Rapid release of the data to the academic community would solve the problem of continued viability. Experience shows that any database that is not regularly used is almost certain to disappear in short order. Unused data have a short shelf life because of the difficulties of adequately documenting and storing data for future use.

c. Scientific Utility

Access to dense, marine magnetic surveys would be extremely valuable to the geophysical community in several important scientific applications.

i) Improvements in the Accuracy of Plate Tectonic Reconstruction

The data-dense magnetic surveys can be used to place more accurate constraints on the age of the seafloor. Combined with the recently available satellite radar bathymetry (Geosat and ERS-1) measurements, magnetic survey data will make it possible to increase the precision of calculated plate reconstruction rotation parameters including finite rotations associated with the long-term evolution of the Pacific and Atlantic. These rotation parameters are the foundation of most plate tectonic studies.

ii) Analysis of the Jurassic and Cretaceous Quiet Zones

The origin of the magnetic quiet zones, which encompass large areas of the ocean floor, is still unknown. Analysis of dense magnetic surveys would be very helpful for evaluating various proposed models. One idea that could be tested, with fundamental implications for geomagnetism, is that the Jurassic and Cretaceous Quiet Zones have different origins. The Cretaceous Quiet Zones may represent a period of time when the field intensity was strong but the polarity was not reversing, while the Jurassic Quiet Zones may represent a period of time when the field was reversing very rapidly but the intensity was low. High-resolution magnetic surveys could test this idea.

iii) Origin of Intermediate Wavelength Crustal Anomalies

One of the most poorly understood aspects of the crustal magnetic field data is intermediate wavelength anomalies of roughly 500-3,000 wavelengths in size. Anomalies at these wavelengths have been identified in satellite magnetic fields, but their source within the crust (and even their existence) has been difficult to establish and is a matter of debate. There is currently a mismatch in the amplitude of these anomalies by about a factor of two, when sea surface observations are extrapolated for comparison with satellite observations (*e.g.*, NASA MAGSAT). It has been suggested that these differences are caused by satellite altitude errors combining to attenuate the magnitude of an average vector of component data, but they are more probably due to assumptions about interpolation implicit in the upward continuation process. The resolution of this question is important not only in determining the size of intermediate wavelength magnetic anomalies, but also in deciding what can be resolved from magnetic satellite data Current sea surface data sets suffer from inadequate secular variation corrections because of their irregular temporal and spatial distributions, complicating comparisons between surface and satellite observations. The good temporal and spatial resolution of the Navy data could allow resolution of the source of these ambiguities.

iv) Geomagnetism and Earth's Core

The magnetics data collected by the Navy were collected over several decades while the secular (long-term, indefinite duration) variation in Earth's field changed significantly and a series of International Geomagnetic Reference Fields (IGRF) were developed to allow the study of anomalous variations in the field. The detailed, well-navigated, well-calibrated surveys conducted in three dimensions (x, y, t) should provide a database currently unequaled for understanding the details in the evolution of the main geomagnetic field. This information will, in turn, constrain estimates of the flow in the fluid core and interactions between the core and the mantle at the core-mantle boundary.

d. Findings

The findings relative to geomagnetics are:

- Data from the Navy's magnetic surveys could be used to constrain the age of the seafloor, and, combined with satellite radar altimetry measurements, make it possible to refine plate reconstruction rotation parameters, including finite rotations associated with the long-term evolution of the Pacific and Atlantic oceans.

- The availability of high resolution magnetic surveys would help scientists to evaluate various proposed models of plate tectonics.

- The good temporal and spatial resolution of the Navy surface-level magnetic data could better define the source of the ambiguities in intermediate wavelength data from satellites.

- These detailed, well-navigated, and well-calibrated three dimensional measurements should provide a unique database for understanding the details in the evolution of Earth's main magnetic field.

3. GEOSAT ALTIMETRY

a. Data Description

Over the past decade, satellite altimetry has had a considerable impact in the earth sciences. Spacecraft use pulse-limited radars, along with very accurate orbits, to measure the topography of ocean, ice, and land surfaces. Over the ocean, the radar pulse interacts over a wide footprint (3 km) effectively averaging out the surface waves so that small variations (3-5 cm) in sea surface topography can be mapped. Over rougher surfaces such as ice and land, the precision of the topography measurements degrades to several meters. These data have created new fields of research in geodesy, glaciology, marine geology, geophysics, and physical oceanography.

The small bumps and dips in the ocean surface (0.03-10 m) follow the equipotential surface of Earth's gravity field, or geoid, so satellite altimeter measurements of sea surface topography can be used to recover marine gravity anomalies. At short wavelengths (<200 km), the gravity field mimics the seafloor topography. Thus, satellite altimeter data provide important reconnaissance information over vast areas of largely uncharted seafloor, such as the Southern Ocean and Antarctic Margins.

Figure 9 shows a sample color shaded relief image (at left) of sea surface gravity anomalies over the Southwest Indian Ridge south of South Africa derived from declassified Geosat/Geodetic Mission (GM) and other altimeter data. The right-hand image in Figure 9 is a color shaded relief image of seafloor topography *predicted* from the data in the left-hand image along with available shipboard depth soundings. Both images are illuminated from the southeast.

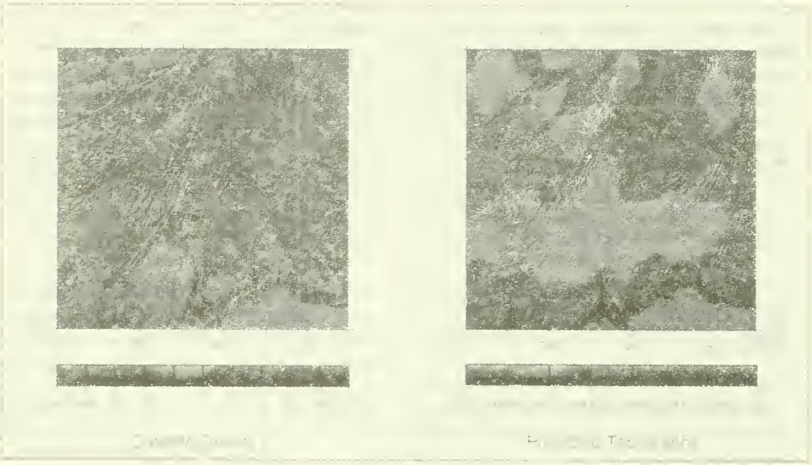
Satellite data quality (1-2 mgal on a 10-15 km wavelength) is currently considered to be better than the standard regional type of survey that was run in the previous 25 years by oceanographers and oil explorers (1 mgal of acceleration is about 10^{6} times the pull of gravity). However, the quality is not as good as the new high-resolution data that are being collected in the oceans today, or as good as the new gradiometer data obtained from the Navy system at sea. The new high-resolution data and the unclassified gradiometer data have an accuracy of about 0.1 mgal on a 500 to 1000 meter wavelength thanks to the availability of high-quality GPS data.

Individual Geosat profiles have a precision of about 6 mgal and along-track resolution of 30-50 km. The close spacing of the profiles (4 km) supports a cross-track resolution that is better than the along-track resolution. This redundancy enables one to construct a two-dimensional gravity field having equally good resolution in all directions (25 km full-wavelength).

b. Accessibility

The Geosat altimeter was launched by the U.S. Navy in March 1985 and provided data until October 1989. Its primary geodetic mission was to map the marine gravity field at a high spatial resolution on a global basis. Because of their military value at the time, most of the data collected during the first 18 months of the mission remain classified, although data from the Southern Ocean (south of 30°S) were declassified in 1992. Some limited results based on the still-classified data have been published by those having access.

FIGURE 9. GEOSAT MEASURED SEA SURFACE GRAVITY ANOMALIES AND PREDICTED SEAFLOOR TOPOGRAPHY IN THE SOUTHERN INDIAN OCEAN



Large scale features of Earth's sub-surface structure are revealed through the use of altimetry measurements from space.

The left figure illustrates Geosat geodetic repeat mission data south of 30° S that has previously been declassified. At right is a depiction of seafloor topography derived from these Geosat altimetry data Comparison with shipboard bathymetry data would show a high degree of correlation between the directly measured (ship) and inferred (satellite) bathymetry

c. Scientific Utility

Geodynamic applications of the satellite altimetry data include:

- Location of uncharted features for planning detailed shipboard surveys and improving bathymetric charts;
- Investigation of seafloor morphology and isostasy;
- Identification of fracture zone trends for improving plate reconstruction models;
- Determination of the global distribution and loading histories of undersea volcanoes;
- Location of marine sedimentary basins for hydrocarbon exploration;
- Constraining shallow mantle convection processes including those beneath mid-ocean ridges.

A review of the available unclassified and declassified data suggests that additional altimetry from either Geosat or European Space Agency ERS-1 coverage will lead to a major improvement in the resolution of the marine gravity field, especially in the low latitude regions.

In July 1991, the European Space Agency launched the ERS-1 spacecraft into a high inclination (98.5°) low altitude (780 km) orbit similar to the Geosat orbit. While its primary mission is to collect synthetic aperture radar (SAR) images, it also carries a pulse-limited radar altimeter that is similar in design to the altimeters aboard Seasat and Geosat. In April 1994, ERS-1 began a geodetic mapping phase along a dense 168-day repeat ground track. Two 168-day missions have been completed by ERS-1 and it is now possible to "see" any features that are "seen" in the Geosat GM data, as the measurement precision and spatial resolutions of the two data sets are similar.

If the Geosat GM data were declassified, the ERS-1 and Geosat data could be combined to improve the resolving power slightly beyond the capabilities of either data set alone. Declassification of Geosat GM data would be particularly beneficial in the equatorial regions, for several reasons. First, the ground track spacing of the orbits is largest at the equator, and hence the resolving power of the data sets is least. Second, the ERS-1 orbit is more polar than Geosat, so that at the equator ERS-1 is not expected to resolve the east component of gravity as well as the north component of gravity. Third, there are a number of important outstanding scientific problems in this area.

In addition to the value of Geosat data for inferring marine gravity fields, the Geosat GM data are important in studying global change. The GM data were acquired during an important time in the El Niño cycle. The release of the GM data would extend the range of time available for studying the seasonal and interannual sea-level changes and allow better calibration of long-range forecasting models. The release of the raw GM data would allow the calculations of sea level change between GM and ERS-1 or Topex/Poseidon.

d. Findings

The findings relative to Geosat Altimetry are:

- **It is evident that there will be significant improvements in the accuracy and resolution of the marine gravity field north of 30°S if Geosat classified high-track-density data become available. Such availability would support a variety of geodynamic applications.**

- **The availability of the Geosat data will extend the range of time available for studying sea level changes that are possibly associated with the El Niño cycle.**

4. SEAFLOOR SEDIMENT PROPERTIES

a. Data Description

The academic community does not have a complete, comprehensive, digital database of sediment thickness and sediment type. The Navy has developed such a database and has incorporated it in a sea-floor acoustic reflection loss model, Low Frequency Bottom Loss (LFBL). The global sediment properties database has been derived from a variety of classified and unclassified sources, including open ocean survey operations and seafloor measurements (cores and reflection profiling) taken in shallow waters around the world, as well as use of coring data from the Deep Sea Drilling Project (DSDP), the International Program of Ocean Drilling, and the Ocean Drilling Program. In addition, the Navy has databases containing a variety of information about sediment subsurface structures (*e.g.*, salt domes) that are also unique.

Figures 10 and 11, taken together, present both global scale (Figure 10) and regional scale (Figure 11) representations of surface sediment type and sediment thickness on the seafloor. These figures illustrate the quality and coverage of some of the data types currently available in the Navy's unique global seafloor sediment properties database.

b. Accessibility

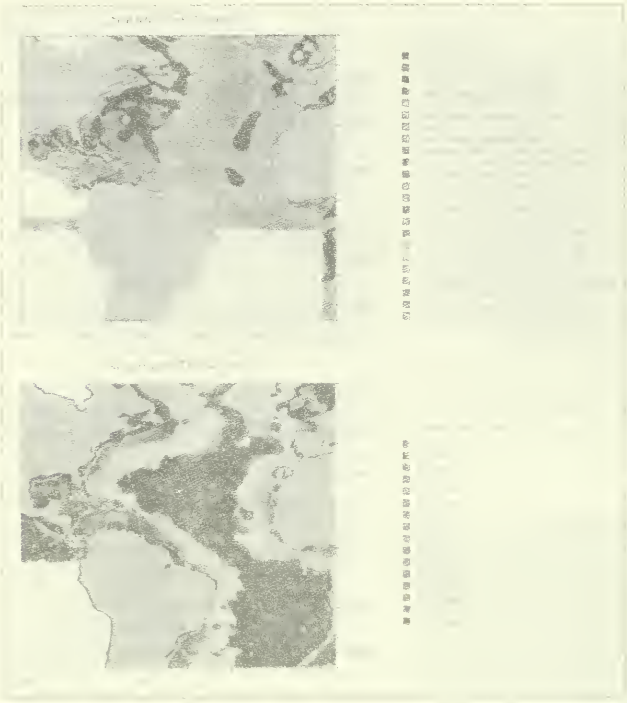
The LFBL acoustic reflection loss model, which was the Navy's rationale for developing the sediments database, is actually composed of two distinct parts: a database of geophysical and acoustic parameters over seafloor regions, and an acoustic model, which calculates acoustic bottom loss for selected frequencies across a full range of acoustic grazing angles. The data in the first LFBL construction were derived from unclassified sources. Further refinement and data additions by NAVOCEANO led to the classification of the LFBL. MEDEA's major interest is in the sediment thickness and sediment type sub-files. Although unclassified, the LFBL sediment thickness and sediment type files have not been distributed outside the Navy's oceanographic/acoustic community.

The Navy also maintains a Geological Laboratory database of site specific bottom cores and grab samples. This database has both restricted and classified content.

c. Scientific Utility

The release and unrestricted distribution of the sediment databases, including the thickness and sediment type parts of LFBL and other databases containing information about subsurface structures, would provide the academic community

Figure 10. Example of Seafloor Sediment Type and Thickness Data



The seafloor was characterized by the Navy on a global basis, primarily for use in acoustic (sonar) models.

This figure shows an example of the sediment types and sediment thickness (expressed as seconds of two-way travel time) for much of the Atlantic Ocean.

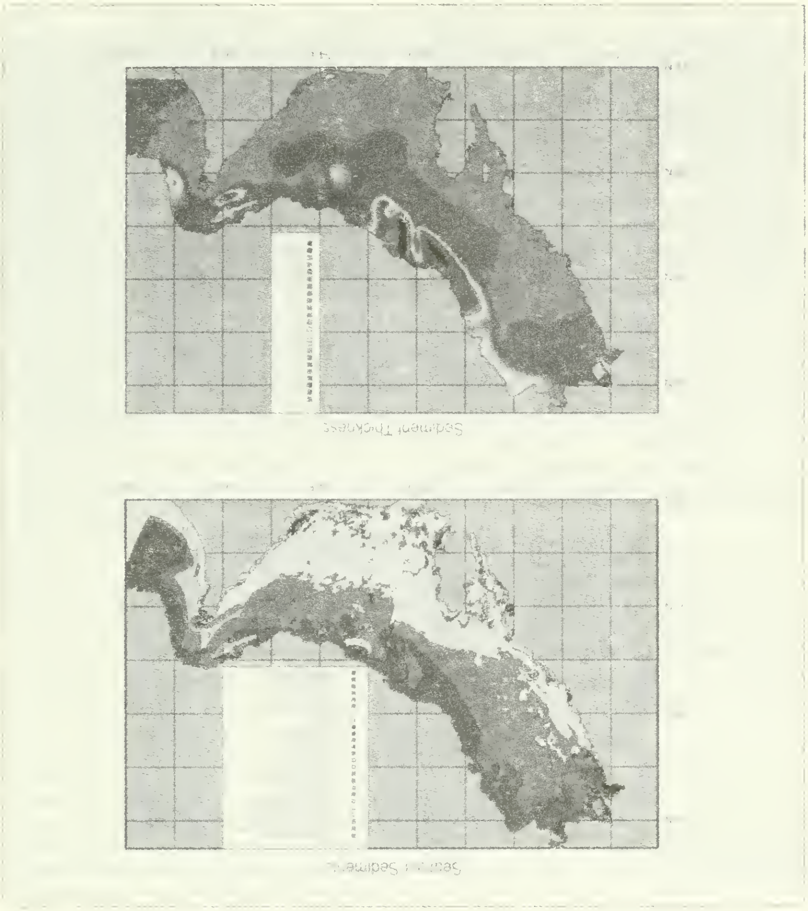
The mid-Atlantic ridge is seen in both illustrations, but most plainly in the region of very thin sediments (≤0.05 sec). Also to be noted is the small region of very thick sediments of the Mississippi Fan, a portion of which was seen through the "lens" of gravity data in Figure 6.

with its first, albeit somewhat limited, global database of sediment characteristics.

Applications of interest include the construction of much more accurate geological maps of the seafloor, providing an environmental baseline and guide to the distribution of natural resources. The descriptions of the physical composition and grain size distribution of the sediments contained in the Navy data could help to significantly improve our understanding of the occurrence of sub-bottom features such as salt domes. Distribution of sediments will also allow research scientists to study in greater detail seafloor processes such as deposition and erosion of sediments by ocean currents.

We anticipate that the quality of the data across this database to be quite variable, but the availability of this global compilation would provide a starting point and background for further refinement. Data from the Ocean Drilling Program and other coring programs were incorporated in the initial configuration. As similar data become available these data can be added and the database improved and expanded beyond its use as an acoustic model subcomponent.

FIGURE 11. REGIONAL ILLUSTRATION OF SEDIMENT TYPE AND SEDIMENT THICKNESS



In selected regional ocean areas, the detail of sediment data in the Navy's database is increased and there is content more specific to each area.

Shown here is the Persian Gulf. Like many ocean areas in proximity to land having low relief, the sediment in the Persian Gulf is seen to be very thin (<5m) except near the outflows of rivers, where thicknesses are ≥ 20m In this figure unconsolidated sediment thickness is given in meters.

Given the detail depicted in this figure, it is important to remember that the civilian community has no digital database on a global or regional basis of seafloor sediment properties that approaches this level of detail.

The Navy's classified collection of bottom sediments and cores available in a relational database could augment the Ocean Drilling Program worldwide data set. Applications of interest include the construction of highly accurate geological maps to provide an extension of onshore mapping, an environmental baseline, and a guide for natural resources exploration. The descriptions of the physical composition and grain size distribution of the sediments could help commercial users locate oil-saturated sediments, locate titanium and manganese deposits, and map salt domes, which can act as petroleum traps or influence migration pathways. Composite records of the distribution of sediments (like the LFBL sediment thickness data) could assist in the study of sea bottom processes such as current activity, erosion, and deposition.

The thickness of sediment deposits near coastlines provides important constraints on the nature of the evolution of continental margins that are subject to the same thermal decay, loading, and elastic flexure as the seafloor. Seismologists observe low frequency surface waves that propagate across the ocean basins and continental margins, but do not have access to global maps of sediment thickness to use in estimating its effect on the dispersion characteristics of the modes.

d. Findings

The findings relative to seafloor sediment properties are:

- The Navy's global ocean sediment thickness database is unclassified, though it has not been generally accessible. Its value and uniqueness strongly support the conclusion that it should be publicly distributed.

- The associated seafloor sediment type database should also be made publicly available.

- The bottom sediments data can be of use to geophysicists for studies of the solid earth, including investigations of seismic wave propagation.

- Geological maps constructed with these data as well as extensions to onshore mapping can provide data for environmental business, natural resource exploration, and paleo-productivity assessments.

C. SEA ICE

1. HISTORICAL ICE MORPHOLOGY

a. Data Description

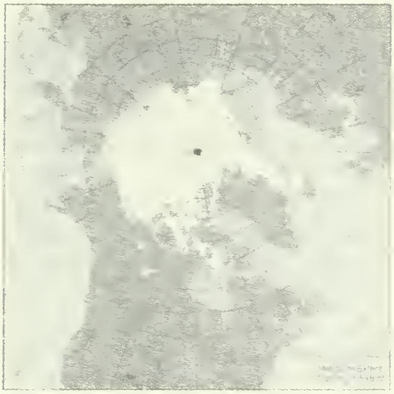
Temporal records of Arctic ice extent, ice type, ice drift, and ice draft are collected and stored in Navy classified archives. The Navy's interest in ice is related to its operations at northern latitudes where sea ice can be both a hazard and a haven. The ice provides both an optical and acoustical cover for submarines, and the operation of surface ships is constrained by ice boundaries and drift. Ice thickness is important for submarine operation in the Arctic region since under-ice safety is related to knowing where the thinner ice might be found or where deep ice keel obstructions exist.

A particularly impressive data set available at the National Ice Center (NIC) is a detailed historical analysis of sea ice conditions over the Arctic Outer Continental Shelf. This data set provides a decade of ice observations prior to the launch of LANDSAT in 1972 and is the result of an inventive compilation from a wide variety of data sources. There is an excellent chance that this data set is superior to any compiled set available elsewhere. These data exist in the form of hand drawn charts exhibiting ice edge and ice condition information compiled from a variety of classified and unclassified sources.

Figure 12 (unclassified) shows the minimum and maximum extent of ice edges. The Navy's classified Historical Ice Morphology charts cannot be shown here, but their contents are primarily depictions of the ice edge and ice conditions (concentration, type, etc.) in hand-drawn chart format with a temporal granularity of one week.

The well-known mean drift of Arctic ice is illustrated in Figure 13. Arrows represent the direction of the ice drift across the Arctic Basin, with the speed being proportional to the length of the arrow. This Arctic ice drift, combined with the seasonal effects of warming/cooling and variable snow cover, will require much more granularity for depicting ice conditions, should scientific research into topics like climate warming be initiated.

FIGURE 12. MAXIMUM AND MINIMUM EXTENT OF ICE EDGES



The extent of the Arctic ice cover undergoes a large seasonal fluctuation, between an average of about 16 million square kilometers in winter (March) to 8 million square kilometers in summer (August). Year to year variations are large in specific sectors, but averaged over all longitudes, they are only a few percent.

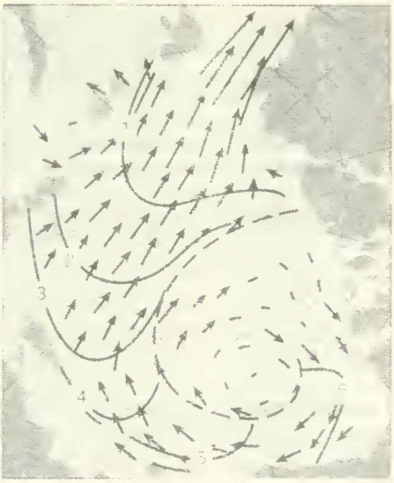
The northernmost position of the Arctic sea ice edge at each longitude is shown in white for summer and grey for winter.

The Navy's Historical Ice Morphology data are a refinement of the long term averaged view shown here, and include information about ice conditions and composition on finer spatial and temporal scales.

b. Accessibility

Most of the Navy's best historical ice morphology data for the Arctic are classified today. A closer review is needed to determine how this data set could be made more accessible. Although NIC does not provide direct project support to non-governmental organizations, the primary NIC unclassified derived product (the bi-weekly global sea ice assessment) is available to the general public via computer file transfers. NIC also indirectly supports a variety of private activities such as the sea lift resupply of communities along the North Slope of Alaska and winter fishing fleet operations in the Bering Sea.

FIGURE 13. AVERAGE ANNUAL ICE DRIFT IN THE ARCTIC BASIN



Ice drift direction and speed data are represented by vectors

Arrows represent the direction of ice drift across the Arctic Basin; the speed is proportional to the length of the arrow. The ice movement "fronts" are shown in yearly intervals

Solid lines labeled 1-6 indicate the likely number of years that ice will survive before it exits the Arctic Ocean through the Fram Strait (between Greenland and Spitzbergen) or melts in the warm water near the coast during summer.

c. Scientific Utility

The sea ice cover of the polar regions exhibits complex interactions and feedback that affect both local Arctic climate as well as the climate of more distant, inhabited temperate regions of the globe. Both the extent and the thickness of sea ice are believed to be particularly sensitive to subtle changes in climate, a sensitivity that is believed to be particularly important over the outer continental shelves of the Arctic. Also, model calculations for a wide range of greenhouse warming scenarios predict the poleward amplification of climate change, which should be accompanied by a reduction in the sea ice cover.

To date, the prediction of significant changes in the ice cover has not been borne out by measurements. However, this conclusion is primarily based on the analysis of passive microwave data collected by satellite sensor systems, which are limited in both spatial resolution and temporal extent. Clearly the Navy's historical ice morphology data, which are both detailed and predate satellite data by a decade, have much to offer here. This information is also of considerable use to climatologists; to scientists studying the near-shore transfer of pollutants; to individuals studying near-coastal sea ice dynamics, as well as polynya (open water "leads" in the ice) and bottom water formation. These data could also be important to modelers carrying out studies of processes occurring over continental shelves.

It should also be noted that the historical ice morphology charts are also of considerable importance both to groups interested in developing coastal sea routes across the Arctic region between the Atlantic and Pacific oceans, and to companies assessing the operational difficulties of extracting the assumed large petroleum reserves from the Arctic Shelves. In both cases the Navy data would allow an improved assessment of hazards and trends.

Finally, the Navy data should prove invaluable to individuals investigating primary production in the food chain over the Arctic Shelves. Although the Arctic region has for many years been assumed to be biologically barren, recent evidence suggests that this is particularly not true over the continental shelves. Indeed the ice edges in the Bering and Chuckchi seas are proving to be areas of intense biological activity including important fisheries. The improved data on the variability of shelf ice conditions should definitely contribute to the analysis of observed variations in biological stocks over the Arctic Shelves. For instance, in the Bering Sea research suggests that there are direct relations between ice conditions and oceanographic factors that favor the survival of juvenile stocks of important varieties of fish.

With respect to these scientific questions, it is not the current realtime products of the National Ice Center that are of prime importance. Instead it is the accumulated historical database of global sea ice information. It is important that the release of this accumulated historical database be continued through the National Snow and Ice Data Center (NSIDC).

d. Findings

The findings relative to historical ice morphology are:

- **The reanalysis of the Ice Morphology data set, currently underway at the NIC, should be completed with consideration given to releasing a sanitized form of the final product as an unclassified data set.**

- **Classified holdings of accumulated historical sea ice information in the Arctic region, if released, would contribute significantly to the inventory of available data and facilitate climate and ocean thermal studies in a significant way.**

- **This information would be of considerable use because it is an "undiscovered" historical record that will fill gaps in studies of ice/water thermodynamic and hydrodynamic processes and transport.**

- **The pre-LANDSAT data should be digitized and a means sought for its release in an unclassified derived product.**

- **A separate, classified ice morphology archive at NAVMETOCCOM should be retained. This archive would contain additional high-resolution analyses obtained from classified sources.**

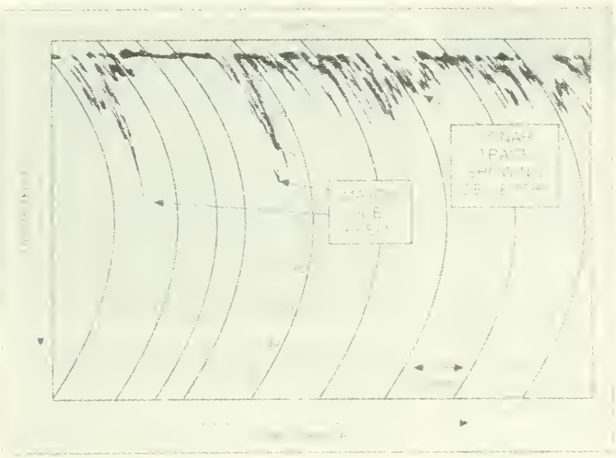
2. ICE KEEL DEPTH ACOUSTIC DATA

a. Data Description

The only reliable methods of obtaining extended profiles of ice keel drafts (depths), and by implication, ice thickness, are upward-looking, narrow-beam sonars (ULS) mounted on submarines (Lagrangian data), or mounted at the top of subsurface floats moored to the seafloor (Eulerian data). Methods to deduce ice thickness from parameters observable by satellite are in an experimental stage and will, in any case, yield regional or average thicknesses and "ice type" rather than data with the high spatial resolution of the sonar method.

Submarines have been acquiring sonar ice draft data since the first Arctic crossing by Nautilus in 1957. In assessing the

Figure 14. Example of a Submarine Upward-Looking Sonar Record from September 1993



Paper strip charts from analog recorders generated during an under ice experiment show the variations in ice keel depths in the central Arctic region. Several major ice keels extend about 30-40 feet below the surface.

The horizontal scale is actually time, but given the ship speed from ship's logs it also represents distance traveled under the ice. In the case shown the major horizontal division is approximately 0.7 nautical miles.

This example has been declassified by the Navy through omitting certain details that would be necessary for scientific use including some level of detail in location and time.

scientific value of these data it should be borne in mind that their primary purpose has been to avoid obstacles (icebergs and deep pressure ridge keels) and locate thin ice for surfacing. Moored sonars have been placed entirely in the service of scientific research, but they have been in operation only during the past four years.

Between 1957 and 1975, the submarine sonar data were recorded in an analog mode. Starting in 1976, a digital recording system was added to the analog recorder on a number (but not all) of the cruises. The advantage of the digital system, which is referred to as DIPS (Digital Ice Profiling System), is that it greatly facilitates analysis of the data after the cruise has been completed. The reason that the analog system was retained was that it provided the crew with realtime information on the position of the bottom of the ice overhead. Figure 14 shows an example of these analog recordings.

There is a large inventory of analog data that has not been reduced from the original paper strip chart format (Table 5). Accompanying these data are the associated records of location, time, depth, etc. necessary to process the data into a scientifically useful series of ice keel depth data points at specified locations. From detailed discussions with the Navy concerning these data, we have concluded that the analog records could produce mean ice draft that would be accurate to within ≈ 0.5 m, a value that would be similar to the results of the analysis of the DIPS data. In addition, since both analog and DIPS data exist on a number of cruises, a quite exact estimate can be obtained of any systematic differences between these two data sets as used on exactly the same ice. These analog results would therefore also yield valuable information on keel depths and distributions.

The current data holdings (including the DIPS data) are from slightly more than 50 deployments comprising approximately 1,800 days under the ice and 380,000 nm of ice information (Table 6). Almost all cruises up to and including the present have analog records of the sonar information while only 20 cruises have DIPS data, 4 of which had major recording problems and are not useful, and 12 of which have been preprocessed.

b. Accessibility

Except for the five earliest cruises (*e.g.*, the Nautilus cruises) all of the Navy's raw ice keel sonar data remain classified because the complete records necessarily contain submarine tracks

TABLE 5. EXISTING ANALOG SUBMARINE ICE KEEL DRAFT ACOUSTIC DATA

YEAR	TRACK MILES OF DATA	NO. PAPER RECORD ROLLS	YEAR	TRACK MILES OF DATA	NO. PAPER RECORD ROLLS
1957	0+	9	1982	9,198	71
1958	2,463	17	1983	13.916	104
1959	3,090	31	1984	19,900	Undet
1960	6,003	57	1985	12,200	Undet
1962	0+	69	1986	17,085	166
1967	1,075	7	1987	11,478	79
1969	9,551	75	1988	10,649	88
1970	6,286	94	1990	11,476	75
1973	1,806	45	1991	3.989	25
1975	0+	63	1993	0+	23
1979	9.139	65	1994	0+	16
1981	7,503	37			

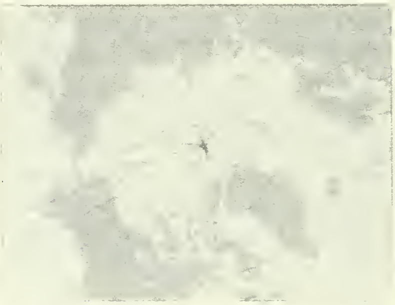
TABLE 6. EXISTING DIGITAL (MAGNETIC TAPE) RECORDS OF A SUBMARINE ICE KEEL DRAFT ACOUSTIC DATA

YEAR	NAUTICAL MILES	YEAR	NAUTICAL MILES
1976	7,641	1988	15,396
1977	11,425	1989	3,614+
1978	8,498	1990	12.063
1982	7,837	1991	14,342
1984	8,072	1992	15,231
1985	69,621	1993	11,673
1986	20,321	1994	9,098
1987	20,324		

under the Arctic ice, which have operational sensitivity. However, as these events age, the security concerns diminish and the Navy has openly discussed some Arctic cruises like that of the Nautilus, and papers have been published using such data.

Certain classified aspects of under ice data sets could be preserved while still providing the environmental community with data that retain their usefulness. Although no raw data are likely to be declassified soon, the Navy has agreed[4] to provide, in unclassified form, all existing submarine ice exercise acoustic data taken within the geographic area shown in Figure 15. This figure also shows a depiction of previously released submarine tracks through 1982.

FIGURE 15. DATA RELEASE AREA AND HISTORICAL SUBMARINE TRACKS



This figure shows the boundaries of the area approved by the Navy (CNO) in 1992 for release of environmental data from Arctic submarine exercises. Also shown for this area are the submarine tracks of Arctic ice exercises through 1982.

Present Navy policies require that in order to be released, acoustic ice data lying within the designated area shown in Figure 15 can be released only if the associated positional data have been coarse grained in time and space. We have examined this matter within context of the coarse graining parameters specified by the Navy and see it as no impediment to full scientific exploitation of the data. For future scientific Arctic cruises, data release has been approved for the slightly larger area shown in Figure 16.

c. Scientific Utility

Since Nansen's Arctic journey, drifting ice camps of various sorts have been in operation for approximately 100 station-years. Ice thickness observations obtained by drilling holes or measuring ice freeboard have established an average ice thickness in the central Arctic region of about 3 meters, with a large variance on small spatial scales. However, from these physical, location-specific data, over the past century no discernible secular trend has been documented.

Submarine ice profiles are a valuable data source for ice draft and ice process studies. The spatial and the temporal coverage that these data supply is important for investigations studying both large- and small-scale variations and trends in the state of the ice pack. From the data that are eligible for release, one

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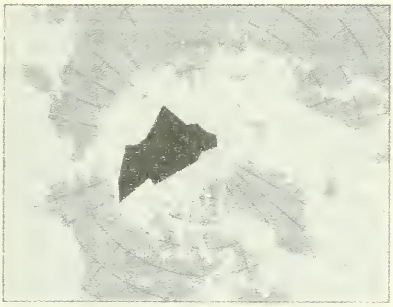
[4] The scientific community has yet to "test" this policy with new data requests

FIGURE 16. AREA APPROVED FOR RELEASE OF FUTURE ARCTIC DATA



This figure shows the boundaries of the area approved by the Navy for release of environmental data from future Arctic submarine exercises.

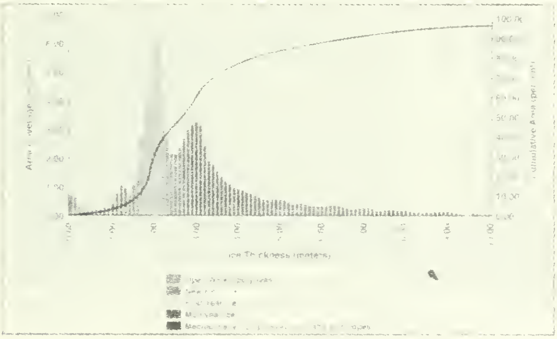
could hope to develop seasonal distributions of ice thickness extending over many years and covering important sections of the Arctic basin.

The Navy's ice draft acoustic data could also prove valuable in developing and assessing methods for estimating ice thickness and especially, ice thickness distribution, by satellite and aircraft remote sensing (*e.g.*, ERS-1 and Radarsat). For example, many synthetic aperture radar images exist over the Arctic region, especially the Beaufort Sea. Efforts to use these images to estimate sea ice thickness are hampered by the lack of calibrated surface measurements. The Navy's ice draft data could fill this gap if the track along which the data were collected could be located in the SAR image. Sufficiently precise techniques do exist to locate both SAR image pixels and the submarine track. However, since release of detailed track data may be difficult, and since few such tracks will happen to fall within existing SAR images, only a limited number of detailed submarine ice draft acoustic data with detailed locations would be needed. Use of these acoustic ice draft data would support the long-term scientific goal of creating ice thickness maps of the Arctic regions using both aircraft and satellite remote sensing.

One product that it would be possible to extract in a straightforward way from the ice draft acoustic data would be the distribution of ice thickness. An example of what one "snapshot" distribution might look like is shown in Figure 17 taken from the Southern Beaufort Sea (using data unrelated to the Navy's classified data discussed here).

During the cold season (September to May), new ice forms wherever existing ice cover splits and diverges. Subsequent motion under the influence of winds and ocean currents causes the ice to shear, converge, raft, and ridge. The result is an ice thickness distribution such as the one shown. This thickness distribution is an important indicator of mechanical forces and of heat exchange between atmosphere and ocean. Only upward-looking sonar is capable of obtaining this information efficiently and with the necessary accuracy.

FIGURE 17. DISTRIBUTION OF ICE DRAFTS IN THE SOUTHERN BEAUFORT SEA



The small maximum at 0m represents open water and very new ice having a thickness of only a few centimeters. The poorly defined maximum at ice thicknesses near 1 meter represents ice that has grown as a result of ice divergence during the past 1-2 months. The largest peak, near 2 meters, is first year ice that started growing during the previous autumn. The broad maximum near 3 meters represents the preponderant population of multiyear ice. The tail of the distribution toward large thicknesses (greater than 4 meters, extending to 15 meters) represents mechanically compressed ice such as ridges and rafts.

The line rising to nearly 100%, associated with the scale at the right, gives the cumulative area. Thus approximately 75% of the area measured contains ice that is 4 meters thick or less, and approximately 95% is less than 10 meters.

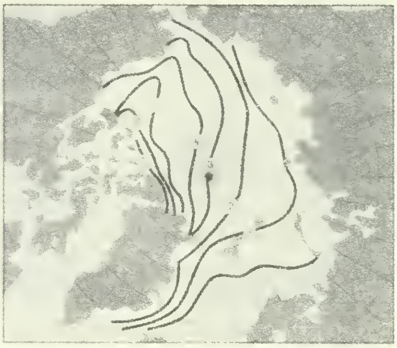
The overall picture of Arctic ice thickness has been developed by several investigators from a variety of sources. One such portrayal is shown in Figure 18, depicting the mean winter ice thickness developed from some of the early Navy data (adapted from publicly available data).

The Navy also holds some of the acoustic ice draft data in processed forms. For its own purposes the Navy has developed classified and unclassified databases of under ice features. For instance, ice information was needed in acoustic models that were developed to predict sound propagation loss in the Arctic region. Since 1989 the Navy has analyzed the DIPS data from 14 of the 20 cruises on which the DIPS system was deployed. As a result of these analyses, 10 statistical parameters including mean ice draft, rms ice draft, and standard deviation of the mean ice draft, as well as a variety of parameters describing ridging, were calculated for each nautical mile when ice was overhead. These data are available in two different databases.

The first database remains classified because it includes position and timing details for individual cruises as well as the specific data extracted from individual cruises. In that database, results are generally binned into 60 x 60 nm regions. The values are interpolated for regions where data are not available, and a clear distinction is made between real information and interpolated values. The second unclassified database is entitled Ice Profile Database V3.1. The data upon which V3.1 is based are identical to the classified database. In addition, the 60x60 nm geographic binning is retained. However, the data are grouped into two seasons, fall and spring, and the results of all the data obtained for each 60x60 nm block are averaged. Values are interpolated for blocks where data are unavailable, and information is not provided to allow the user to distinguish real average values from interpolated values.

In its present format the Ice Profile Database V3.1 cannot be exploited by the scientific community. Because of the global averaging, it is impossible to look at temporal variations in ice conditions, potentially the most interesting aspect that could be studied. Also, the grouping of data into spring and fall does not provide adequate temporal resolution to allow sorting of changes with time (although it may not be necessary to know time and place exactly). Another problem with V3.1 is that measured data cannot be distinguished from interpolated numbers that are filling data voids.

Figure 18. Mean Ice Draft from Various Early Submarine Cruises



Over the Arctic region, ice thickness composites have been constructed from previously released submarine acoustic and a variety of supporting data.

This figure shows one such depiction of mean winter ice thicknesses. Not surprisingly the mean is driven by the thick multiyear ice causing the peak at 3m seen in Figure 17.

Although the distribution in Figure 17 results from measurements in one part of the Beaufort sea, and Figure 18 shows a long term winter mean for the entire Arctic region, the two depictions are quite consistent.

The Profile Database could be made useful if the data were only averaged within individual cruises and within each 60 x 60 nm box (30x30 nm boxes would be preferable). Further, the box averages should be coupled with a year and a time of year. If these changes were made, scientists probably could perform more detailed analyses of ice patterns and trends.

The practical accessibility of the analog data is limited by its present format. If these data are ever to be analyzed and thereby made available for further studies, now is the time. The early charts are nearly 40 years old. Yet, all the information required for an adequate analysis still exists at the Arctic Submarine Laboratory.

With regard to the analog data, we expect that current state-of-the-art image analysis techniques could prove extremely useful in speeding the processing of the analog data. If it were decided to analyze these data, all of the data should be analyzed, even those data from areas outside of the releasable geographic region.

d. Findings

The findings relative to ice keel depth acoustic data are:

- The data from upward-looking submarine sonar measurements of ice are the only quantitative measures of under ice structure available to studies of under-ice topography and climate.

- Archival analog data from about 50 exercises still exist. These data were found to be of sufficient quality that they could be reduced and processed to create a digital database. The analog data, in classified form, should be digitized and put into a database along with the supporting information (tracks), and then reduced to a geolocated time series of ice thickness. This classified database should then be archived at NAVOCEANO pending possible declassification, prior to which it should be made accessible in its classified form to appropriately cleared scientists.

- All of the data, both analog and digital, within the area already identified by the Navy as containing releasable data for future submarine scientific cruises, should be provided to the scientific community for its use (in accord with current Navy plans).

- The unclassified Ice Profile Database V3.1 could be a useful composite reference containing ice structure if modified to contain more detailed data (less averaging).

- The Navy's ice draft acoustic data, accumulated over about 30 years, is likely to prove valuable in developing more accurate methods for measuring ice thickness by aircraft and satellite remote sensing (e.g. ERS-1 and Radarsat).

- Both unclassified and classified data should be processed and archived in such a way that temporal changes of ice thickness and thickness distributions are fully preserved. Regional averages and their changes in time can be derived as needed if the primary data are fully documented.

D. OCEAN VOLUME AND BOUNDARY PROPERTIES

1. REALTIME SALINITY AND TEMPERATURE FIELDS (GOODS)

a. Data Description

The Global Oceanographic Observation Data Set (GOODS) contains a wide variety of ocean measurements collected from drifting buoys, moorings, ships, and aircraft (primarily vertical profiles of temperature and temperature/salinity data with some observed sound speed profiles and surface temperature values, similar to MOODS). These are near realtime data that are relayed to FNMOC and NAVOCEANO and loaded into a database for access the next day. GOODS coverage is worldwide. These daily observations provide a new look into ocean processes that has previously been unavailable to most of the ocean science community.

Data are stored in an on-line accessible database for a period of approximately three months. To the panel's knowledge, the GOODS data set is the only realtime, quality-controlled, network-accessible collection of surface ocean observations available anywhere. Availability of this data set is of primary interest to ocean modelers and analysts. It would be of immense immediate interest to various researchers for validating satellite observations.

Figure 19 illustrates the global nature of one component of GOODS holdings, those in the "restricted" category. It is important to note the large number of measurements, even within this limited category, that are typically accomplished in the short period of five months.

b. Accessibility

Many of the GOODS data are obtained from unclassified sources. However, Navy ships also contribute to the databases, and the locations of these ships are usually classified while they are out of port. As a result, some individual data entries in the database are classified, and because of the regulations governing processing and storage of classified digital data, the entire GOODS database must be handled as classified.

Data are stored on-line and can be accessed electronically. Data accessed at a summary level (like sea surface temperature contours) can be used as unclassified material.

c. Scientific Utility

If researchers are afforded access to the data, the near realtime view afforded by GOODS would open important new applications to the ocean science community.

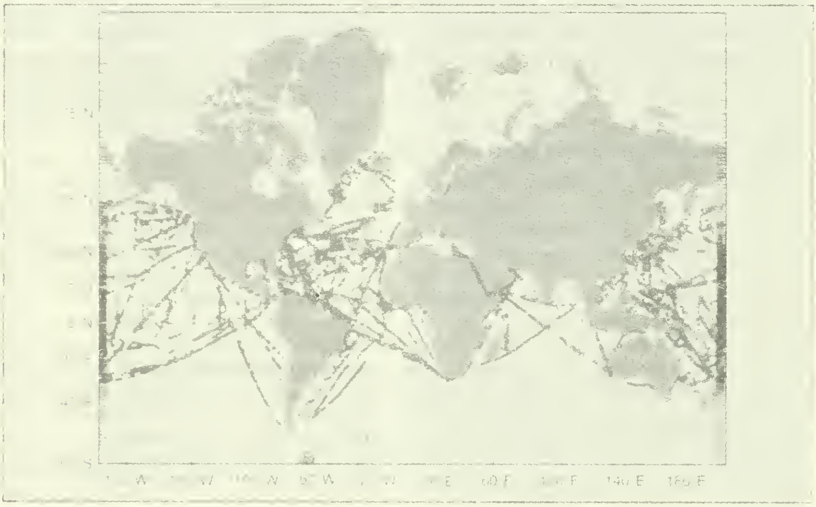
- Ship observations and other sampling schemes could be adapted to conform to the state of the ocean. Such adaptive sampling would greatly increase the efficiency of limited sampling resources, much as access to near realtime satellite imagery has done in the past decade.

- Many satellite algorithms make use of *in situ* observations for either sensor calibration or validation. Access to GOODS would allow researchers to test the performance of such algorithms and assess their quality based on comparisons between the satellite-derived observations and the data located in GOODS. Reducing the delay between the comparison of *in situ* and satellite observations would greatly improve the utility of remote sensing data.

- Numerical models of ocean processes are evolving toward the use of data assimilation techniques and *nowcasting* of the current state of the ocean. Similar to procedures used in weather forecasting, ocean models could incorporate GOODS data directly into the nowcast system.

- The techniques used in GOODS could eventually migrate into operational systems to support commercial and regulatory needs. For example, near real-time observations could be used to forecast warming events that might be critical for near shore aquaculture activities.

Figure 19. Global Data Holdings for GOODS, June–October, 1994



Shown here are the locations at which "restricted" GOODS data were collected during the period June-October in 1994.

Even over the span of a few months the GOODS data are spatially diverse and contain frequent samples. The actual data include temperature profiles and may include salinity profiles and other measurements depending on the collection platform and its instrumentation.

The total volume of GOODS data, including the public access and classified data, is significantly greater than that shown here.

Oceanography is steadily moving toward nowcasts (and eventually forecasts) of ocean circulation patterns. Access to near realtime data will be a critical element of such models. Many other activities, including ship and aircraft observations, would benefit greatly by this near realtime view. The present system focuses primarily on physical observations such as currents, temperature, and salinity. We encourage NAVOCEANO to examine new data types, such as bio-optical measurements, as a wider variety of autonomous sensors become available and are widely distributed in the oceans.

d. Findings

The findings relative to realtime salinity and temperature fields (GOODS) are:

- **Although the largest part of the GOODS database is unclassified it is not generally accessible. It is recommended that steps be taken to explore access to this database via the Internet where it would get its most productive use.**

- **Nowcasting of the ocean circulation and temperature is the future direction of oceanography, and GOODS data would make a significant contribution.**

2. ARCHIVAL SALINITY AND TEMPERATURE FIELDS (MOODS)

a. Data Description

The Master Oceanographic Observation Data Set (MOODS) is probably the largest collection of *in situ* oceanographic observations that has been synthesized into a single coherent database. The MOODS data set covers the time period from 1900 to the present. MOODS contains primarily vertical profiles of temperature and temperature/salinity data with some observed sound speed profiles and some surface temperature values. The highest depth resolution of the MOODS data is one meter. Examples of ocean thermal structure data extracted from MOODS are given in Figure 20 for two nearby but dissimilar ocean areas.

Figure 21 again shows dissimilar data from nearby ocean areas, this time in the Mediterranean Sea. Unlike Figure 20 which shows many individual temperature profiles, Figure 21 shows only the envelope of temperature and salinity profiles. Ship surveys such as the ones resulting in the data shown in Figure 21 commonly produce both temperature and salinity (and other) data, whereas aircraft surveys normally provide only temperature data as depicted in Figure 20.

To gain some understanding of the spatial sampling of MOODS data, Figure 22 illustrates the locations of *public domain* MOODS survey data for the Norwegian and Barents seas in the winter season.

b. Accessibility

Currently MOODS is only available to the Navy and the DoD community. The unclassified MOODS database contains publicly available data as well as restricted and/or sensitive but unclassified data. Disclosure of the restricted and/or sensitive data may be controlled by bilateral international data exchange agreements or other understandings. Coupled with the unclassified/restricted/sensitive data, there is also a classified MOODS database which contains data at various classification levels.

NAVOCEANO transfers unclassified data collected for MOODS to the National Oceanographic Data Center (NODC) for distribution in the public domain. In theory, this should ensure a timely progression of these data to general use.

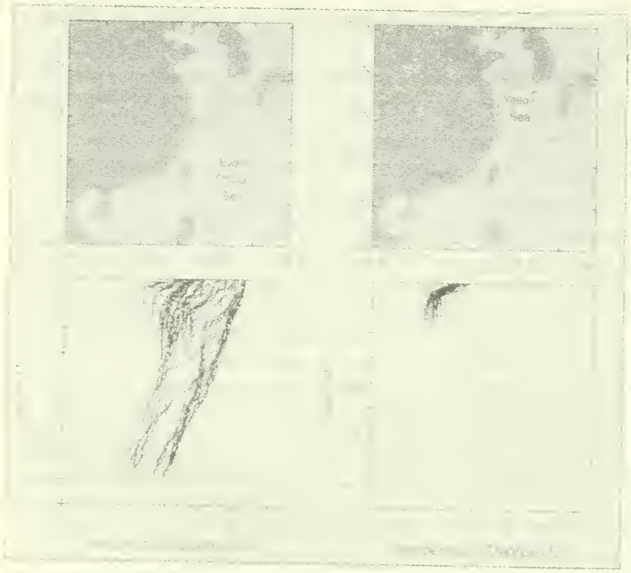
Each vertical data cast in the MOODS database contains a data classification code in the data header, including the data distribution statement and reason for restriction. A comparison of the amount of data categorized by distribution statement is illustrated in Figure 23. A representative area (the Norwegian and Barents seas) was chosen as a baseline for comparison of the different types and categories of data.

c. Scientific Utility

Improved descriptions of the oceanic density field are fundamental to our understanding of the ocean's circulation. Such descriptions provide a basis for estimates of mean circulation as well as analyses of low frequency changes in circulation, *e.g.*, decadal fluctuations in North Atlantic salinity.

General availability of the original MOODS database from NAVOCEANO to the civilian oceanographic community would significantly enhance education and research in ocean sciences. It is unclear to us whether access to either the restricted or the classified data would significantly enhance the value of current

Figure 20. Sample MOODS Aircraft Survey Data



MOODS aircraft-collected data consist of temperature measurements vs. depth (i.e., profiles) along with location and time references.

Over ocean areas the ocean structure represented by ocean temperature changes on various spatial scales. Here we see the cooler (7°C to 14 °C) waters of the shallow Yellow Sea on the right and the warmer (10° C to 26° C) waters of the deeper East China Sea on the left. In this case only temperature data were collected.

ocean data archives, since the distribution of these data with respect to the unclassified holdings has not been examined in detail. It has been determined, however, that in many cases the non-public data primarily improves the spatial sampling of the public data rather than providing data in areas or time periods having no public data.

To quantify the uniqueness of the restricted data types in MOODS, we recommend that NAVOCEANO review the MOODS holdings and develop products that address the uniqueness of these particular holdings. If the result of this process suggests that the classified holdings do not contribute significantly to the overall ocean database, we would recommend that the public domain data be released for general open distribution. On the other hand, if such a review of the data suggests that the restricted and/or sensitive data holdings provide significant insight into ocean processes, then we would recommend more general disclosure of the overall database.

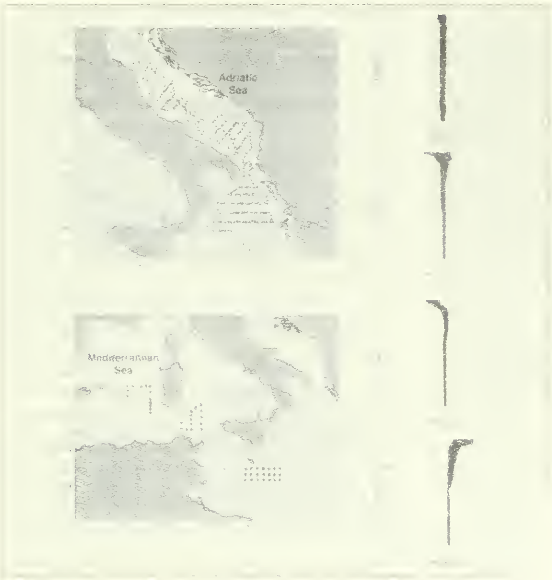
d. Findings

The findings relative to archival salinity and temperature fields (MOODS) are:

- The general availability of the original MOODS database to the civilian oceanographic community would significantly enhance the ocean climatological data inventory available for public sector education and research in ocean sciences.

- An investigation into the restricted/sensitive data or classified data in MOODS should be conducted to determine if these data would enhance the database enough to argue for further release of classified MOODS holdings.

FIGURE 21. SAMPLE MOODS SHIP SURVEY DATA



MOODS ship-collected data consist of both temperature and salinity versus depth profiles along with location and time references. For clarity only the envelopes of the individual temperature and salinity profiles are shown. The profile envelopes exhibit the near-isothermal and isohaline waters of the Adriatic on the top, and the waters of the central Mediterranean having an upper ocean layer with strong gradients in both parameters.

3. OCEAN OPTICS AND BIOLUMINESCENCE

a. Data Description

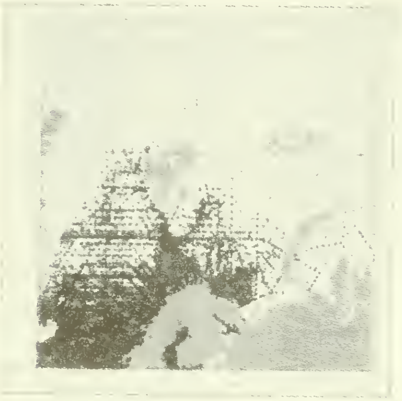
The Navy's interest in optics of the ocean derives from such issues as the potential for optical detection of underwater objects and laser bathymetry, as well as for environmental concerns, such as the detection of fuel leaks, determination of the toxicity of antifoulant coatings, detection of chemical compounds, or location of contaminated sediments. Similarly, civilian environmental measurement applications are present at both the micro and macro levels. Micro level analyses of contaminated water and macro level analyses, for example, global ocean color, are complementary methods of measuring ocean "health." Color and transmission properties help determine the presence of effluents and estimate their rates of dissipation or dispersal. Bioluminescence is tied to ocean life processes and can be a convenient measurement tool of broader ocean "health."

Figure 24 shows a measurement of bioluminescence activity in a portion of the East China Sea at a measurement depth of 3m.

Space-based techniques for the estimation of ocean color and ocean clarity are in development. Older Navy data are less voluminous both temporally and spatially than that permitted by present techniques. While remote sensing techniques are being refined, there still is the need for *in situ* and at-depth measurements that cannot be duplicated without using ships at sea. These data must also be available to provide a baseline for remote sensing techniques.

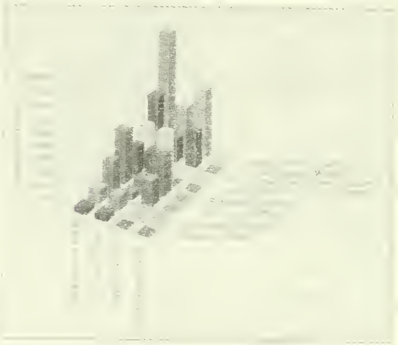
More optical data are being collected in the coastal zones of the world with the change in focus of U.S. Navy operations. These regions are especially challenging because optical properties are far more complex and regionally specific, and because the scales of variability are much smaller. Traditional sampling

FIGURE 22. MOODS SURVEY LOCATIONS IN THE NORWEGIAN AND BARENTS SEAS



Each color point represents the location of a particular oceanographic measurement and indicates the type of profile that was collected and placed into MOODS. A blue point indicates a location where a depth/temperature profile is available. A red point denotes a combined depth/temperature/salinity profile. The map plots all of the data points available in the public domain for the winter season.

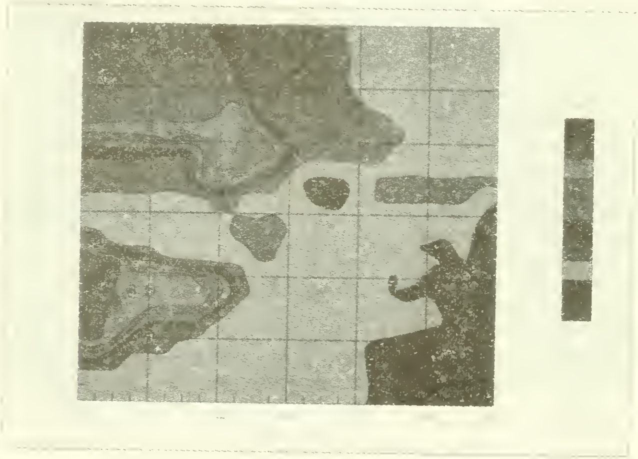
FIGURE 23. QUANTITIES OF DATA CONTAINED IN MOODS DISTRIBUTION CATEGORIES



This figure compares the numbers of MOODS profiles that are available in the various categories of accessibility.

A large amount of MOODS data are already in the public domain category. Many of the non-public domain data are not classified, but restricted (usually as a result of some bilateral international agreement). It is not necessarily the case, however, that the potential for gaining public access to currently restricted data is greater than that for currently classified data.

FIGURE 24. SHIP SURVEY BIOLUMINESCENCE DATA IN THE EAST CHINA SEA



These data show the intensity of bioluminescence at a depth of 3 meters. The maximum activity is in the southwestern part of the area and the minimum in the southeastern portion, which includes a part of the Ryukyu Island chain.

Unlike many ocean characteristics that vary by small amounts over even very large areas, these data exhibit variations greater than an order of magnitude.

These measurements were made in the same area as portions of the aircraft surveys depicted in Figure 20.

methods that rely on deployment of expensive, one-of-a-kind sensors are inadequate to meet the challenge of optical research in the coastal zone.

b. Accessibility

Generally there is no public access to these data since the majority are classified. The Naval Oceanographic Office has collected an extensive set of optical and bioluminescence measurements of the world's oceans, primarily in classified form. These ship observations include both underway and on-station measurements. Although the data are primarily located in areas of specific interest to the Navy, they represent an extensive set of unique measurements. Most of these data are available through official (classified) data reports, but they are not available electronically through a relational database.

c. Scientific Utility

Improved characterization of optical parameters in littoral access will be of immediate help to studies of ocean health, living marine resources, and basic research. Coastal studies are a prime example of how the operational and research communities would benefit by joint data sharing and research programs. For example, the next-generation satellite ocean color sensors will provide much better measurements in these complex coastal waters. Access to both civilian and operational databases of *in situ* observations would significantly improve the quality of the satellite retrievals for both communities.

A second example of utility would be in the area of *in situ* sensor design. The research community is moving toward less capable (in terms of signal-to-noise ratios, number of spectral bands, etc.) sensors that are dramatically less expensive. Such sensors are suitable for deployment in greater densities (to resolve small-scale variability) or in areas where loss of sensors is likely (such as in areas of heavy fishing activity). These sensors would benefit both the operational and research communities. We encourage NAVOCEANO to continue to foster the exchange of information on sensor development.

d. Findings

The findings relative to ocean optics and bioluminescence are:

- **NAVOCEANO should continue to foster the exchange of information on optical sensor development since this drives data collection capabilities for both civilian and Navy communities.**

- **Coastal studies are a prime example of how the Navy operational and civilian research communities would benefit by joint research programs, thus taking advantage of the post-cold-war Navy focus on littoral regions.**

4. MARINE BATHYMETRY

a. Data Description

Bathymetry is the science of measuring ocean depths to determine seafloor topography. Seafloor bathymetry, and global topography in general, represents the most fundamental of geophysical databases. Oceanographic, meteorological, and geologic studies depend upon accurate descriptions of morphology to understand the magnitude and lateral scale of variability within the earth, ocean, and atmosphere. In the past, national and international bodies have sought to incorporate as much survey data as possible to generate reliable and accurate maps of the seafloor. NAVOCEANO has assisted in this important process by making survey data available and has supported unclassified databases such as the Digital Bathymetric Database (DBDB).

The Navy has been interested in ocean depth not only because of navigation, but because of the channeling of ocean signals and noise. To support acoustic analyses, the bathymetry of the world has been digitized into databases with five arc minute grids, with some geographic areas at 2, 1, 0.5, and 0.1 arc minute resolutions. All ocean areas north of 78° S are covered, as well as depths up to the 200 m contour line near the coasts (shallower depths are interpolated values). Bathymetric values are in uncorrected meters measured acoustically and are referred to a sound speed of 1,500 meters/sec.

Figure 25 shows three dimensional representations of ocean bathymetry of a small test area of the northeast Pacific at two resolutions, high resolution (0.1 arc minute) and low resolution (1.0 arc minute). Bathymetric data having a resolution of 0.1 arc minute are normally classified by the Navy. However, this particular example was taken from a data collection in a test area used by the Navy for understanding the utility of high resolution data.

The original multibeam bathymetric sonar data are archived at NAVOCEANO and can be accessed in their original raw form. Returning to these raw sonar data could provide researchers with the highest level of detail available. These data were used in the construction of the gridded database summaries. Multibeam data from the Sonar Array Survey System (SASS) became available starting in the mid-1960s. SeaBeam data collection began in 1987. SIMRAD systems, including EM-100 (1992) and now the EM-121A and SeaBeam 2000/2012 systems (1995), are the latest bathymetric mapping equipment in use today.

b. Accessibility

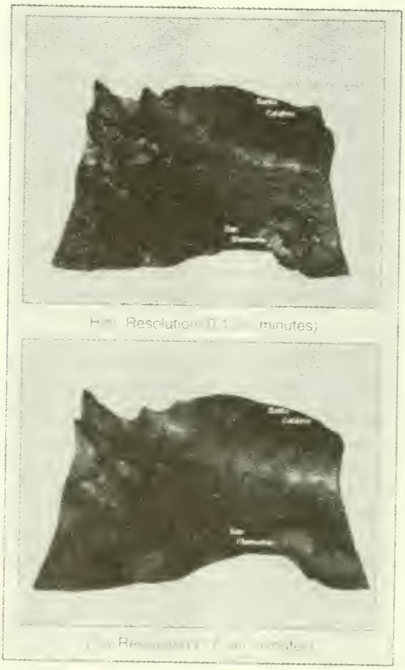
Accessibility to some of the bathymetric databases is possible at the unclassified level except for sensitive regions where the location of detailed surveys may compromise location-specific issues. Detailed gravity surveys that include bathymetry data were generally conducted at locations that are not associated with such systems and where gravity variability is high. There are also high resolution databases that are classified in their entirety. Distribution of the DBDBs to government users is through the Defense Mapping Agency with assistance from the Naval Oceanographic Office. A 5 arc minute resolution, global grid DBDB is available to the public through the National Geophysical Data Center. There is an effort underway to produce an unclassified database with variable resolution (DBDB-V) that would incorporate some 0.5 arc minute data.

Multibeam bathymetric sonar data are mostly classified or restricted. Restricted data are often the result of a cooperative data collection with a foreign government or under a bilateral agreement. The host government would have to give its approval before these data dissemination restrictions could be removed. While possible, this could be very difficult in practice.

c. Scientific Utility

The joint availability of magnetics and seafloor topography data would greatly improve plate tectonic reconstructions.

FIGURE 25. SAMPLE BATHYMETRY DATA AT HIGH AND LOW RESOLUTIONS



This composite figure shows the topography of a small section of the seafloor off the coast of California. The upper illustration is from bathymetric data having a resolution of 0.1 arc minute (i.e., 0.1 nautical mile). The lower illustration is from bathymetric data having a resolution, an order of magnitude coarser, of 1.0 arc minute (i.e., 1 nautical mile). In areas where there is little relief (e.g., the center of the area) the two representations differ little. In areas of significant relief, the southwestern corner for example, the high resolution data show a much greater degree of irregularity.

Detailed bathymetry data, accompanying marine magnetics data, and geoid data from Geosat/ERS-1 would allow detailed reconstructions of plate motions through time to include the oldest Jurassic and Cretaceous lithosphere.

As new oceanic lithosphere is created at mid-ocean ridges and spreads away from volcanic centers, the lithosphere cools, becomes more dense, and sinks. For some time, a square root relationship between age and depth of the seafloor has been understood as a manifestation of the diffusion process, which conducts the heat into the overlying ocean. However, the accuracy of seafloor depth data and ambiguities in the age of the topography (available from magnetics data) have resulted in numerous hypotheses of spatial and tectonic variations in the cooling process. The availability of these highly accurate and finely sampled data would allow, for the first time, a detailed study of the spatial variations in this important evolutionary process.

The oceanic lithosphere acts as an elastic plate of time-varying thickness. As lithosphere ages, volcanoes are sometimes erupted onto the plate (*e.g.*, Hawaii) and the loading causes the lithosphere to flex. Often such flexure results in *moats* around the volcanoes, and the spatial characteristics of the flexure can be used to estimate the thickness of the plate and the age of loading. Frequently the lithosphere can be reheated after cooling; previously submerged islands can again ascend above the ocean's surface. Outward of oceanic trenches, old, cold lithosphere is flexed by the forces associated with the subduction of the lithosphere to great depths. Again the spatial characteristics can be used to provide an estimate of the elastic thickness. Detailed ocean bottom topography, enhanced by geoid and gravity data, would greatly expand upon the data sets available for studying the importance of the elastic lithosphere in understanding the vertical component of tectonics in the oceans.

The North Pacific contains many linear volcanic chains that are poorly defined on current bathymetric charts. Most scientists believe that these chains formed as the Pacific plate moved over numerous hot spots. However, some chains may be caused by volcanism associated with plate deformation. High-resolution bathymetry would help address this issue by revealing the spatial relationships among the volcanoes. Moreover, high-resolution maps would reveal the detailed morphology of individual structures. The important morphological features are the flatness of the seamount or guyot, the number of rift flanks, and preferential alignment of the rift flanks perhaps related to plate-wide stress patterns. Finally, detailed bathymetry is needed for magnetic modeling of individual seamounts to establish their paleolatitude of formation, as well as magnetic reversal patterns along volcanic chains.

The Navy's bathymetry data are truly a national asset. The compilation and gridding represents an estimated 176 man-years of effort, and the survey data on which the data are based are never likely to be duplicated. Accurate and detailed measurements of the ocean depth can only be done using ships, which is both expensive and time consuming.

Raw, side-scan sonar data offer an exciting opportunity to augment relatively low-resolution surveys, which have been available for several years in limited areas (*e.g.*, GLORIA). The availability of high-resolution side-scan sonar coverage will have major implications for the oil and gas industry in mapping seafloor faults and fractures that control oil or gas seeps, produce subsea freshwater springs, and contribute to slope instability. Hazards to navigation and existing pipelines can be much more accurately located, facilitating pipeline repair or ship routing around hazards.

d. Findings

The findings relative to marine bathymetry are:

- The joint availability of magnetics and seafloor topography data, in combination, would greatly improve the accuracy of plate tectonic reconstructions and materially aid planning of at-sea experiments and a variety of ocean measurements and analyses.

- It is very important that the Navy's planned release of DBDB-V is achieved soon.

- A determination should be made concerning the level of utility afforded by DBDB-V if significant amounts of the 0.5 arc minute resolution database (DBDB-0.5) are not released and incorporated into DBDB-V.

- Provided that the release of DBDB-V occurs, there will be a smaller potential scientific benefit to the release of the remaining classified data. However, should the planned release of DBDB-V with 0.5 arc minute data not occur, we strongly believe that a review of the classification policies themselves should be undertaken with a view toward making such a declassification possible.

E. ADDITIONAL CONSIDERATIONS

1. GENERALIZED DIGITAL ENVIRONMENTAL MODEL (GDEM)

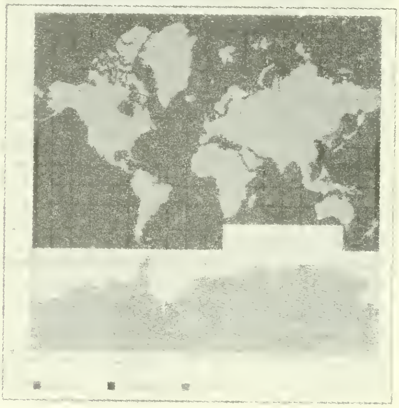
The GDEM is one of the Navy's standard climatology databases providing information on the temperature and salinity of the ocean. It is a derived database in that it does not contain actual oceanographic observations, but instead consists of statistical representations of the temperature and salinity fields drawn from MOODS. MOODS contains about five million observations worldwide. GDEM was constructed by fitting polynomial curves (with the exception of the surface layer, 0-400 meters) to each depth profile from MOODS and averaging all the equivalent coefficients within each 30 arc minute spatial cell. The surface layer coefficients are those that give the appropriate amplitude response to a filter function. The global results were then gridded with interpolated values filling in any voids. Using these coefficients this model can reconstruct a representative climatological vertical profile of ocean temperature and salinity at any location in the Northern Hemisphere for any of the four seasons. GDEM profiles are available for ocean areas where the water depths exceed 100 meters, except for the Mediterranean, Red Sea, and Sea of Japan where the cutoff depth is 50 meters, and the Persian Gulf and Yellow Sea where it is 0 meters. An update of the public domain GDEM in progress will result in some areas having 10 arc minute resolution. Figure 26 shows where GDEM ocean models exist and some of their important characteristics.

A recent comparison between GDEM and the Levitus Climatology suggests that GDEM provides results very similar to the Levitus Climatology, which is extensively used by oceanographers to initialize numerical global and regional circulation models. These models are providing significant insight into ocean circulation and the role of the oceans in global climate. For areas of strong ocean currents, such as the Gulf Stream and Kuroshio, an unsmoothed version of the GDEM results is available. This unsmoothed version has been reported to provide a better representation of the density structure than does the Levitus Climatology.

V-GDEM stands for Variability for the Generalized Digital Environmental Model, and provides an envelope of plus or minus two standard deviations around the GDEM profile for each 30 arc minute grid cell. While GDEM can be obtained for various parts of the world oceans via the Internet with anonymous File Transfer Protocol (FTP), V-GDEM and the high-resolution GDEM are not available via the Internet, and the Arctic GDEM, while not classified, is restricted to Navy-approved users.

GDEM and V-GDEM could be very useful to a number of oceanographers working on circulation, air-sea exchange, and climate issues. We suspect that many oceanographers may not be aware of these models, their structure, and how they might be obtained. It would seem desirable to make the oceanographic community as a whole more aware of these databases. We are certain that the oceanographic community would like to have the Arctic GDEM available for use as well as the higher resolution shallow seas GDEM. As a broader segment of the oceanographic community uses these products, we expect these models to become better known and used, and that recommendations for enhancements will be forthcoming.

FIGURE 26. GDEM COVERAGE



This figure shows the ocean areas where GDEM ocean profile data models of various resolutions exist.

Table 7 summarizes the most important characteristics of the models. While the lowest resolution GDEM ocean data models have been developed for nearly the entire globe, the higher resolution models exist only for limited regional ocean areas.

Table 7. Components of the GDEM Database

BASIN	AREA	SPATIAL RESOLUTION	MINIMUM DEPTH
Arctic	north of 65N	30 minutes	100 meters
North Atlantic	0-65N	30 minutes	100 meters
South Atlantic	60S-0, 70W-20E	30 minutes	100 meters
North Pacific	0-65N	30 minutes	100 meters
South Pacific	60S-0, 145E-70W	30 minutes	100 meters
Mediterranean	5W-42E	30 minutes	50 meters
Indian Ocean	N of 40S, 20-145E	30 minutes	100 meters
Red Sea	N of 40S, 20-145E	30 minutes	50 meters
Persian Gulf	N of 40S, 20-145E	10 minutes	0 meters
Sea of Japan	34.5N-52N	10 minutes	50 meters
Yellow Sea	23-41N, 116-133E	10 minutes	0 meters

2. ARCTIC BUOY PROGRAM

This unclassified Arctic data buoy program has been very effective in providing realtime ice motion and surface pressure data over the Arctic Basin and, as the sophistication and flexibility of the buoys continues to improve, the collection of an expanded suite of meteorological and oceanographic parameters is now possible. Not only is this data set essential to effective NIC operations, it is also generally useful to a variety of civilian meteorology and oceanography research programs. By piecing together support from a number of governmental agencies within the United States as well as Canada, Germany, and recently Russia, NIC has been able to continue this important program with great benefit to everyone operating in the Arctic region. This has not always been an easy task but the results have proven to be well worth the effort.

3. COMPREHENSIVE ENVIRONMENTAL ASSESSMENT SYSTEM (CEAS)

CEAS consists of a user-oriented software front-end connected to a series of environmental databases that are often collected by classified government assets in support of Navy operations. These databases have, for the most part, already been discussed in this report. The databases run on public-domain Geographic Resources Analysis Support System (GRASS) software, and can be accessed using the widely available ARC INFO Graphical Information Systems (GIS) format. The databases are relational in that they can be superimposed in multiple layers to provide a data package registered to a common base map. This multi-layered registration enhances the utility of all the data sets in that they can be analyzed in context and in various combinations to suit the user's requirements.

Data contained in the CEAS vary in type, measurement precision, and geographic coverage. General categories of data potentially available include high-resolution bathymetry, bottom sediment properties and characteristics (*e.g.*, thickness, physical properties, grain size, area distribution, acoustical properties), and seafloor roughness. These data are typically analyzed in conjunction with other databases to provide operational information to the military client.

Not all data types are available in all geographic areas; they vary by both density and precision of measurement. In general, coverage includes coastal regions and open oceans where Navy operations have been conducted or might be in the future. These areas include the Persian Gulf, Gulf of Oman, western Pacific Ocean, Mediterranean Sea, and other areas. Significantly, many of the areas already covered are of interest to science and industry, where exploration for natural resources or pollution abatement programs are planned or are underway.

Figure 27 shows one form of data output obtained from CEAS, an identification of various anomalies in the seafloor in the Persian Gulf.

The availability of these data in ARC INFO format makes them attractive to civilian users because they can be easily added to existing databases. Much of the data available from CEAS is already available in terms of general type and regional coverage. However, the value of this system lies in the high quality of the data (resolution and multiple measurements over a lengthy time) and the data now available from previously denied regions.

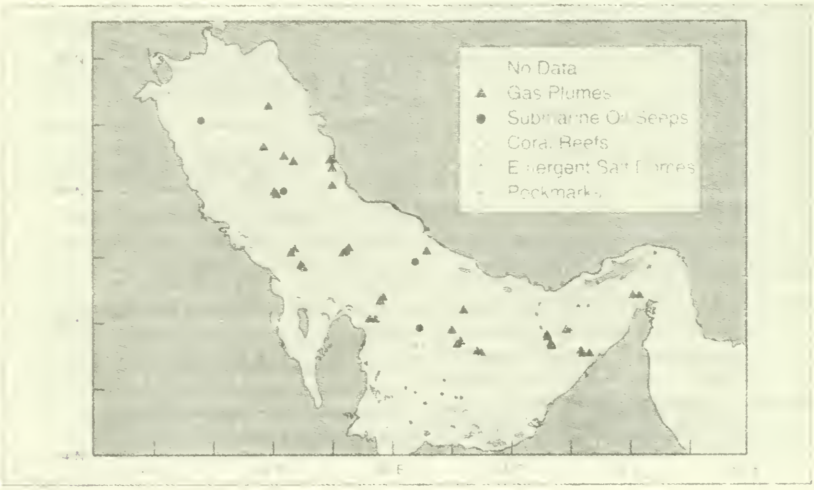
The CEAS database has an effect on a number of marine engineering issues:

- Natural resources exploration—oil and gas, minerals;
- Engineering studies—siting offshore platforms and facilities, port access channels, ice hazards and grounding potential, submarine slump potential and slope stability, undersea cable, and pipeline routing;
- Environmental baseline studies, pollution control;
- Hazards to navigation—detection of shoals, coral reefs, shipwrecks, and abandoned structures; and
- Contribution to global change and solid earth geophysics studies.

CEAS would be particularly useful in developing and applying interpretation methods to remote sensing data from many parts of the world's oceans (e.g. Space Radar Laboratory SAR imagery). CEAS would help provide the "surface truth" to enable interpretation to be done in a cost effective manner. Surface information not only aids in confirming correct interpretations, but allows false interpretations to be discovered and discarded.

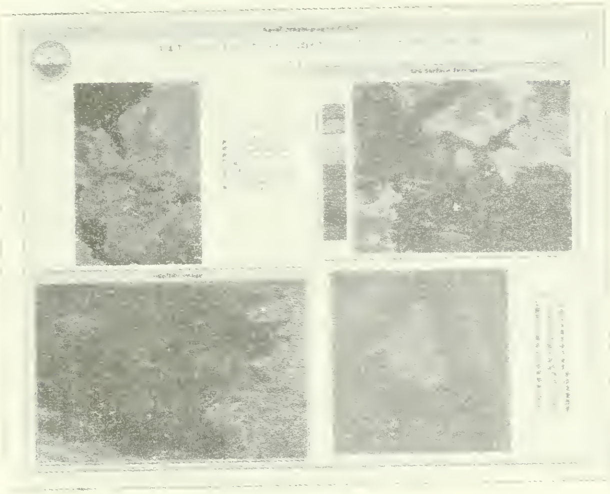
To convey some sense of how CEAS might appear to a user, Figure 28 shows several database access options for the western Atlantic. Depicted are sediment type data, ocean temperature at a specified depth from MOODS, sea surface temperature from satellite data, and acoustic ocean noise.

FIGURE 27. CEAS-GENERATED PLOT OF SEAFLOOR ANOMALIES



This figure shows five different types of seafloor anomalies in the Persian Gulf.

FIGURE 28. EXAMPLE OF CEAS DATABASE ACCESS OPTIONS



CEAS offers the user relativel easy access to an entire variety of NAVOCEANO ocean data.

Included are the seafloor sediments data, bulk properties such as temperature and salinity, satellite data, and some acoustic data.

4. ACOUSTIC DATA AND ACOUSTIC SENSING OF THE OCEAN

Except as mentioned, the MEDEA study did not review or consider the large acoustic data holdings of the Navy. The majority of acoustic data held by NAVOCEANO are the multibeam bathymetric survey data, although there are extensive holdings of ambient noise measurements and transmission loss.

In a broad sense, acoustics is the major measurement tool for ocean environments (bathymetry, distance, bottom roughness, bottom characteristics, seismic noise, etc.). Acoustic measurement systems work well because of the physical transmissivity properties of the water medium. Electromagnetic measurements are not possible in water except over short distances or at very low frequencies. (Not coincidentally, this is why the Navy was interested in sensing for submarines with acoustics.) Therefore, the acoustic measurement data and acoustic measurement expertise resident within the NAVOCEANO oceanographic departments represent a valuable part of the Navy's classified holdings.

Within the acoustic data collected for system development and the systems designed for submarine detection, there are possible opportunities for scientific use of ancillary products. For instance, for many years there has been a interest in data that would reveal long-term trends in ocean noise levels due to shipping. The oceanographic community has long debated the trends in the ocean noise environment and the natural and man-made components of the ocean noise condition and variability.

It is also known that acoustic sensing of seismic events is a sensitive method of measuring undersea seismic activity and variations. Studies by the NOAA-Pacific Marine Environmental Laboratory (PMEL) and others have demonstrated the utility of undersea acoustic data for long range seismic monitoring of ocean seismic activity.

The Navy's acoustic data holdings and acoustic surveillance systems could be given wider use similar to the efforts being carried out within the Strategic Environmental R&D Program's to employ the Integrated Undersea Surveillance System (IUSS) to study endangered whale populations and ocean seismic events.

F. SUMMARY

During the past 30 years the Navy's ocean surveys have systematically collected bathymetry, gravity, magnetics, and salinity/temperature field data on a global basis, in particular, encompassing almost all of the Northern Hemisphere. Altogether more than 100 ship-years of data acquisition have been devoted to this effort. It is highly unlikely that such an effort will ever be repeated. Equally, as with any historical data, the National Ice Center's ice morphology charts from the 1960's and the [illegible] acoustic data from 1970 can never be obtained from any future measurement program.

The major findings of this chapter concern, first, an assessment of the potential [illegible] of the [illegible] to support scientific research should public release become possible. The second dimension concerns a prioritization of these findings in terms of the importance of the research that could be supported.

The major findings identified in this chapter are encapsulated in Tables 8 and 9, which also include a prioritization. We have arrived at this prioritization by considering a number of factors, including the uniqueness of the data, the intrinsic merit of the scientific problems to which the data can be applied, the practical difficulties associated with the use of the data (e.g., the need to convert voluminous uncalibrated analog records to calibrated digital records), and the likelihood that if the data were not made available the civilian community would find some means of replicating it in the foreseeable future.

TABLE 8. FIRST TIER OF SCIENTIFIC SIGNIFICANCE

DATA	DESCRIPTION	SCIENTIFIC UTILITY
Marine Gravity	• Relational database of point observations with latitude, longitude, observation time, free air anomaly, and gravity values, supported with survey, data processing, and statistical information. • Includes Lacoste and Romberg Air Sea Gravity Meter measurements from 1966 to 1983. Bell Aerospace BGM-3 and BGM-5 gravimeters were introduced in 1969.	• Classified marine gravity data provide a view into the underlying geological structure at very short spatial wavelengths currently inaccessible to public users. • Classified gravity data could be used to address three problem areas: (1) spatial variations in gravity at mid-ocean ridges, (2) mapping of [illegible], and (3) the structure of fracture zones. • Classified gravity data would provide the information needed for the Northern Hemisphere to facilitate research into the genesis of Earth's surface.
Current Accessibility: • Entirely classified; no public access.		
Geomagnetics	• Consists of both aircraft (Project Magnet) and satellite vector data. • Ship collected data; consists of scalar point data by latitude and longitude.	• Magnetic surveys could be used to constrain the age of the seafloor accurately, to calculate more accurate plate reconstruction rotation parameters, to analyze the Jurassic and Cretaceous Quiet Zones, and to determine the origin of intermediate wavelength crustal anomalies.
Current Accessibility: • Ship data are classified; no public access; aircraft data are unclassified. • Classified largely because of association with specific ship tracks and ship-track densities.		
Ice Keel Depth Acoustic Data	• Measures ice roughness, ridge frequency, and ice depth (ice draft) below the sea surface. • Data are collected using upward-looking sonar starting with the Arctic journey of SSN Nautilus in 1957. • Approximately 50 data sets exist.	• Data are significant in their own right and as calibration for satellite-borne instruments. • Knowledge of the mechanical redistribution of ice thickness categories would improve our ability to forecast ice conditions for navigation. • Submarine sonar profiles might settle the question of whether or not ice thickness has undergone a secular trend.
Current Accessibility: • Classified; no public access. • Classified primarily because of the association with specific submarine tracks and dates.		
Marine Bathymetry	• A large collection of ocean undersea topography databases. • Gridded digital databases resulting from survey measurements, many using multibeam profilometers. • Data as fine as 0.1 arc minute are available for some areas.	• The accuracy of current representations of the seafloor is not sufficient for many studies. The scientific uses of more accurate data include evaluating the square root relationship between age and depth of the seafloor. • Availability of these finely sampled data would allow for a detailed study of the spatial variations in this important evolutionary process.
Current Accessibility: • Most data having a resolution as high as 1 arc minute are unclassified. • Data at 0.5 arc minute resolution may be declassified as part of the classification review of bathymetric data. • That data chosen for release would then be made part of DBDB-V.		
Geosat Altimetry	• Geosat altimetry measures sea height with world coverage of ± 72 degrees latitude and 3.4 km spacing (1.7 km footprint). • 3 km track spacing at the equator. • 3.5 cm sea height precision.	• Provides important reconnaissance information over vast, largely uncharted areas such as the Southern Ocean and Antarctic margins. • If declassified it could be used with the ERS-1 data to improve the resolving power beyond the capabilities of either data set alone. • Large bathymetric features can be inferred from altimetry sea height data.
Current Accessibility: • Classified north of 30° S; no public access.		

TABLE 9. SECOND TIER OF SCIENTIFIC SIGNIFICANCE

DATA	DESCRIPTION	SCIENTIFIC UTILITY
Ice Morphology	• Describes sea ice conditions and extent over the Arctic Outer Continental Shelf. • Contains information describing ice drift and movement and includes ice edge boundary data in hand drawn charts.	• Data would be of considerable use to climatologists, to scientists studying the near-shore transfer of pollutants; and to individuals studying near-coastal sea ice dynamics. • Data set would also be of particular use to a variety of U.S. companies who are currently faced with difficult off-shore design problems for sites in the marine Arctic region.
Current Accessibility • Classified; no public access • Includes a synthesis of classified and unclassified data.		
Seafloor Sediment Properties	• [illegible] • [illegible]	• Having these data available digitally is a starting point for additional studies. • Availability of an existing global estimate of sediment thickness and approximate sediment types would provide a background against which the quality of future data could be assessed and upgraded.
Current Accessibility • Many of these data are unclassified • Sediment type and sediment thickness is largely unavailable • Some sediments data are restricted because of bilateral international agreements		
Realtime Salinity and Temperature Fields (GOODS)	• [illegible] • [illegible] • [illegible]	• Ship observations could be [illegible] based on the state of the ocean greatly increasing the efficiency of costly ocean sampling resources. • Would allow testing of satellite algorithms for either sensor calibration or validation. • As in weather forecasting, ocean models could incorporate GOODS data into the nowcast system. • Techniques would [illegible] into civil systems to support commercial and regulatory needs.
Current Accessibility • Most [illegible] GOODS are unclassified • [illegible] are classified data because [illegible] providing the data, rendering the entire database inaccessible publicly.		
Archived Temperature and Salinity Fields (MOODS)	• [illegible] • [illegible] • [illegible] Navy [illegible] GOODS	• Public domain transfer capability already in place (NAVOCEANO to NODC). • Can ensure timely progression of data. • Availability to ocean science community would increase ocean data explorations.
Current Accessibility • Majority of MOODS data are unclassified and eventually enter NODC • The classified fraction, mainly in the Arctic region, is classified because of platform locations.		
Ocean Optics and Bioluminescence	• [illegible] measurements • [illegible] prevalent at selected [illegible] • Observations made [illegible] underway and on-station [illegible]	• Next generation satellite ocean color sensors will provide much better measurements in complex coastal waters. Access to both civilian and operational databases of in situ observations would significantly improve the quality of these satellite retrievals. • Could enhance the usage of less capable sensors (less expensive) in greater densities or in areas where loss of sensors is likely.
Current Accessibility • Many of these data are classified.		

III. Improving Capabilities in Ocean Science

A. OVERVIEW

Thus far in this report we have dealt primarily with assessing the scientific utility of specific oceanographic and geophysical databases. Here we will address the more general issue of identifying opportunities for mutual benefit that might arise from a closer technical relationship between academic ocean science and the Navy's oceanographic establishment.

With congressional support, and following recommendations made by the ETF and by MEDEA, the intelligence community has established a program to collect and archive classified NTM imagery data collected from a set of locations that will be regularly surveyed over periods ranging from years to decades. The data are to be used in scientific studies of the global environment, albeit requiring classified access. Some of these measurement sites are ocean areas. One important result of the present MEDEA study has been the realization that scientific exploitation of these ocean fiducial data must involve analytical use of correlative oceanographic data from the data archives of NAVOCEANO. These "correlative data" are in many cases the same as those discussed in Chapter II: ocean thermal and salinity structure, high-resolution bathymetry, etc. The proper scientific exploitation of the ocean fiducial data is, therefore, bound up with access to NAVOCEANO's databases and modeling capabilities.

Section B discusses the rationale for the NTM Global Fiducial Data Program and the need for correlative oceanographic data in its exploitation. Section C addresses the NAVOCEANO data access capabilities, which we believe are important to scientific research in and of themselves, as well as to the exploitation of the ocean fiducial data. The final section, Bridge Building, describes our recommendations for addressing all these issues: exploitation of the NTM fiducial data, use of NAVOCEANO's oceanographic capabilities, and development of closer ties between the Navy and the civilian ocean science community.

B. GLOBAL FIDUCIAL DATA

1. SCIENTIFIC BASIS

The desirability of establishing a long-term record of well-sampled environmental databases on a fixed set of sites has been identified by the scientific community as a critical resource in identifying and analyzing global environmental change. The capability to make systematic observations over many years is essential in gaining an understanding of the fundamental physical and biological processes. Long-term data will reveal variability, such as low-frequency cyclic phenomena and decadal to centennial processes such as global warming, that cannot be resolved in data sets gathered for shorter periods. Long-term observational data also provide long lead-time indications that the global environment trends may be moving in undesirable directions and that actions may be needed to reverse these trends.

There are also discrete, or time-limited, events of both natural (*e.g.*, volcanic eruptions) and manmade origin (*e.g.*, the Kuwait oil field fires, large oil spills, or dumping of radioactive materials in the ocean) with longer term effects on the global system. Studying the effects of such events may provide important insights into how the global environmental system adjusts to these discrete perturbations as well as to longer term changes.

Another dimension of the fiducial data concept involves exploiting the unique capabilities of the nation's classified space-based reconnaissance system. Characteristics of these sensors are complementary to those of civilian and commercial sensor systems. Whereas civilian sensing systems have emphasized relatively low-resolution imaging that covers very large surface areas, classified systems provide high-resolution coverage of relatively small areas. There are also significant differences in their treatments of spectral resolution and bandwidth. Thus classified systems will add a significant dimension to the civilian environmental remote sensing program. Detailed and periodic studies can, therefore, take place at a variety of sites relatively difficult to observe by conventional means. Intense, small-scale studies can also be conducted in oceanic environments, another capability not readily available with civilian sensing systems.

Two types of fiducial sites have been defined—calibration sites and monitoring sites. Calibration sites are those for which data records already exist, especially long-term records of *in situ* data. Calibration sites will frequently be associated with ongoing research studies, thus offering the possibility of prompt assimilation and utility of the NTM fiducial data. Programs associated with fiducial calibration sites include the National Science Foundation's (NSF) Long Term Ecological Research Site Program, the NOAA National Estuarine Research Reserve System and National Marine Sanctuaries Program, and the U.S. Geological Survey's Water, Energy, and Biogeochemical Sites. Monitoring sites are those not having long-term data records.

2. THE NTM GLOBAL FIDUCIAL DATA PROGRAM

The Global Fiducial Data Program is being pursued by the intelligence community, the DoD, and MEDEA, to utilize classified, space-based sensor systems for the purpose of creating a long-term archive of environmental information. With congressional support, the program began in FY 1995 and is expected to continue.

The objective of this program is an archive of classified data that will grow both in size and value over time. As presently envisioned, this archive would be maintained within host U.S. government agencies, with access available to a community of cleared scientists and researchers.

Following historical trends, it is possible that data from certain sensor systems, as well as the operational characteristics of the sensors themselves, may be declassified. This has recently occurred with the declassification of imagery from the earliest U.S. reconnaissance satellite program (CORONA) covering 1960–1972. However, at least initially, the Global Fiducial Data Program will deal with data at the classified level leaving such evolution to the future.

The MEDEA scientific panels have initiated a process for nominating and selecting fiducial sites to support research in a variety of scientific disciplines. When approved by the United States government, a designated set of sites will then be "locked" to a program of long-term data acquisition. The initial set of fiducial sites and data collections will evolve to reflect technological improvements and expanding capabilities. The future tasking and availability of classified systems will necessitate changes and adjustments in the site populations (by type and location) and data acquisition schedules. Within the set of global fiducial sites is a subset of ocean sites where a variety of NTM data will be collected. It is this subset of ocean data that we will consider.

3. SCIENTIFIC EXPLOITATION OF FIDUCIAL DATA

It is expected that ocean fiducial sites will involve both calibration and monitoring sites. Calibration sites can be expected to be limited largely to shallow in-shore waters and beach areas where long-term data records of fixed locations are more common and meaningful. In the open ocean it is expected that scientific exploitation of NTM imagery data will require a combination of *in situ* observations, where the sites can be selected to correspond with planned cruises, and the use of NAVOCEANO's historical archive of oceanographic data.

Effective exploitation of the NTM ocean fiducial data will require simultaneous use of these data in digital form, along with a wide variety of correlative oceanographic data that are resident at the Stennis Space Center (SSC), including both NAVOCEANO and the Naval Research Laboratory (NRL). Figure 29 depicts schematically the idea that the NTM imagery will need to be accompanied by oceanographic data drawn from a variety of Navy databases.

Archiving of the ocean fiducial data at the SSC will facilitate their prompt exploitation for ocean science, whereas waiting until the correlative data are available at the central fiducial archive site would postpone effective use of the ocean fiducial data and jeopardize the very rationale for their collection.

Determination of the number of NTM frames per year that would be made available to populate the database is still required. A 20-year timeframe is envisioned. NAVOCEANO has developed analyses of specific ocean NTM data at its Warfighting Support Center (WSC), where the correlative *in situ* data are available. These results from the WSC should be included in the fiducial database. The WSC could make provisions for a small number of visiting ocean scientists.

FIGURE 29. FIDUCIAL DATA COLLECTION AND CORRELATIVE OCEANOGRAPHIC DATA

This schematic illustration shows the concept of collection of NTM Global Fiducial Data and the use of correlative oceanographic data. For example, the correlative data could involve ocean thermal or salinity structure, bathymetry, or even model outputs involving estimates of ocean currents. Both historicol data, such as that resident in MOODS and "realtime" data such as GOODS, will be useful in this analysis.

Many aspects of the database architecture remain unresolved, and these could drastically affect cost. A prominent example involves the need for an offsite/onsite image browse capability, possibly developed in phases. The first phase might involve only receiving and disseminating NTM data via courier with an on-line connectivity to IDBMS (see the next section) appearing only in a later phase. The WSC could evolve to the complete capability not only for data access but also for the analysis of NTM ocean data. This would further extend NAVOCEANO's capability, building a high-resolution, global oceanography center of excellence.

4. FINDINGS

The findings relative to scientific exploitation of fiducial data are:

- Effective exploitation of the NTM ocean fiducial data will require simultaneous use of these data along with a wide variety of correlative oceanographic data that are currently resident at NAVOCEANO.

- Archiving of the NTM ocean fiducial data at the SSC will facilitate their prompt exploitation for ocean science, whereas waiting until the correlative data are available at the central fiducial archive site would postpone effective use of the ocean fiducial data and jeopardize the very rationale for their collection.

C. ACCESS TO DATA: INTEGRATED DATABASE MANAGEMENT SYSTEM

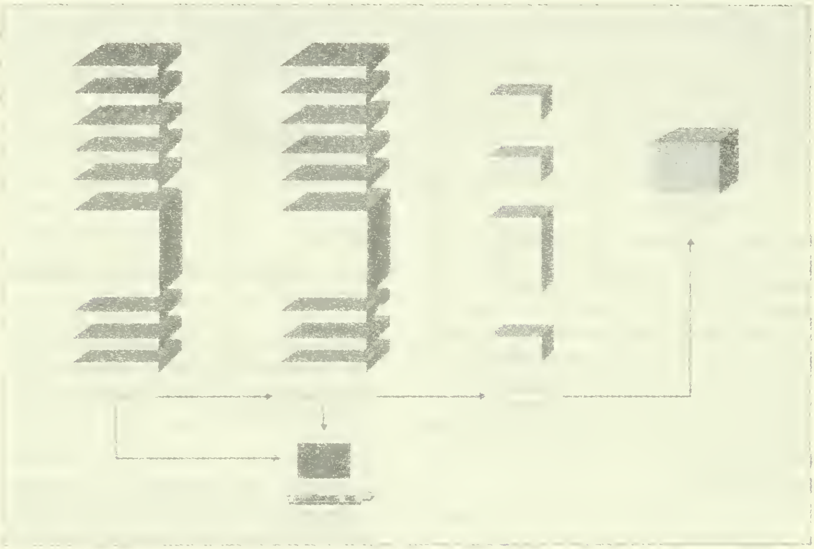
1. BACKGROUND

The results of a 100-ship-year survey program of unprecedented scope, the reduction and analysis of these data, and the development of oceanographic and acoustic modeling tools have left NAVOCEANO with a massive capability that can be cumbersome to access and not at all amenable to external use. Recognizing this problem, the Navy has developed a specialized software system to allow users to interface with an entire suite of oceanographic and geophysical capabilities.

2. INTEGRATED DATABASE MANAGEMENT SYSTEM (IDBMS)

The IDBMS is a computer system designed as an information discovery tool for all NAVOCEANO data. It has always been a NAVOCEANO goal to make its oceanographic information, data, and tools more accessible to scientists. IDBMS functions as a collection system, repository, and distribution tool for a variety of oceanographic data and products. Components of the system include distributed information systems, platform collection systems, primary oceanographic prediction systems, and computer systems for direct product distribution. The overall purpose of the IDBMS is to integrate all components into a functional system for production and distribution of products.

Figure 30. IDBMS Naval and Scientific Applications



This figure shows the integration of spatial and temporal modeling, forecast and performance modeling, and decision support modeling. IDBMS allows access to oceanographic data that can be either measured or gridded/provinced. The data are geo-referenced. A global catalog with a common user interface provides for access and management of tools, data, and information.

While IDBMS was originally intended by the Navy to generate operationally useful products, it could also be used to extract useful information for scientific studies.

Figure 30 illustrates the IDBMS concept, which shows the integration of spatial and temporal modeling, forecast and performance modeling, and decision support modeling. For the Navy's operational use, these data and modeling capabilities are used to develop specific products, such as sonar system performance. However, IDBMS also could be used to extract data and model results having scientific utility—the very data that has been the subject of much of this report.

The information and data in IDBMS are located in a series of IDBMS gateways on both a classified and an unclassified network. Those gateways on the network contain information such as gravity, bathymetry, geomagnetics, and acoustic data, as well as oceanographic projects, satellite processing, physical oceanography data, and performance tools. Access to the information is made available to users on workstations.

The user is directed through the process of IDBMS access through a main menu, with top-level functions made available for tools (accessing tools directly), catalogs (browsing), locations (global overview map), queries (searching for information), and help.

Categories of *measured* IDBMS data are shown in Table 10. Table 11 illustrates sample categories of *gridded/provinced* IDBMS data. Both types of data can be accessed from within IDBMS; however, the applications, models, and tools within IDBMS may use either one type of data or various combinations of both.

TABLE 10. MEASURED IDBMS DATA

DATA CATEGORY	REPRESENTATIVE DATA CONTAINED IN IDBMS
Near Realtime Surface Features	• [illegible]
Acoustics	• ambient noise (beam noise, directional, omnidirectional) • echo response (3.5 KHz) • historical wind speed (mean, observed direction, observed percentile) • acoustic survey horizons (salinity, geophysics, bathymetry, sea surface temperature, seismic) • transmission loss (frequencies, measurements, shots, sound velocity profiles, stations)
Water Column	• [illegible] • [illegible] • [illegible] • [illegible] • [illegible] • [illegible] • [illegible]
Gravity	• point (satellite [Geosat], [illegible])
Bathymetry	• [illegible]
Hydrography	• geodetic control • point depth • navigation aids and hazards
Geomagnetics	• [illegible]
Sediment Characteristics	• bottom grab samples and cores
Geoacoustics	• [illegible] • [illegible] • [illegible] • [illegible] • [illegible]

The architecture consists of a variety of network functions that operate the overall control of IDBMS and the primary input data and data/product dissemination. Gateway functions protect the core data storage and the client access. Central server functions access and manage data ingest, temporary data storage cataloging, and data backup. Another type of server controls the off-line and archive storage of data, as well as acting as a repository for application development and model library functions. The physical architecture of IDBMS consists of Sun Microsystems SPARC-servers, on-line RAID storage, a large-scale computer server, and high-density magnetic tape silo storage all interconnected through information system gateways, local and wide area networks.

3. FINDINGS

The findings relative to the integrated database management system (IDBMS) are:

- IDBMS should be the primary tool to allow external users to interface with NAVOCEANO's oceanographic and geophysical capabilities.

- On-site accessibility by the civilian community, cleared as necessary, should be made available as soon as IDBMS is completed.

- Upon development of a suitable multilevel security operating system, IDBMS should be made accessible over the Internet."

Table 11. Gridded / Provinced IDBMS Information

DATA CATEGORY	DATA CONTAINED IN IDBMS
Measured Acoustics Processed	[illegible] [illegible] [illegible] [illegible]
Water Column (Gridded)	[illegible]
[illegible]	[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
Gravity (Gridded)	[illegible]
[illegible]	[illegible] [illegible]
Geoacoustics (Gridded)	[illegible] [illegible] [illegible] [illegible]

D. BRIDGE BUILDING OPPORTUNITIES IN OCEAN SCIENCE

1. DISCUSSION

The Naval Oceanographic Office has developed truly unique capabilities for synthesizing oceanographic products from diverse and heterogeneous data and displaying the results in useful graphical forms. Beyond the more traditional forms of product generation involving large-scale ocean thermal, salinity, and density fields, this synthesis now includes the development of small-scale regional models in selected ocean areas of naval interest and the exploitation of imagery, including NTM imagery. This product synthesis capability, if it were open to civilian use, would lead to an expanded national benefit. There has been a considerable previous investment of public funds in these capabilities, and scientific access would pave the way for ocean science to move further into small-scale oceanography.

On the other hand, there are currently few effective mechanisms for the flow of information to naval oceanography from academia. It is our conviction that such a flow of information, involving modest "shoe box" measurements or recent progress in dynamic ocean models for example, would be of considerable benefit to naval oceanography generally and to the accuracy of Navy fleet products.

The most important opportunities for bridge building, linking the civilian and Navy oceanography communities, are:

- Deriving greatly enhanced scientific benefit from NAVOCEANO's oceanographic and geophysical capabilities.

- Archiving of the ocean fiducial data in such a way as to facilitate its effective use, and providing the analytical capabilities and correlative data necessary for its scientific exploitation.

- Developing cost-effective mechanisms for much closer coupling between the nation's civilian and military oceanographic establishments to the benefit of both.

2. FINDINGS

The findings relative to bridge building opportunities in ocean science are:

a. Exploitation Center
An exploitation center should be established at the Stennis Space Center. A high data rate local area network would allow access to most classified and unclassified NAVOCEANO databases, models, and product synthesis capabilities to appropriately cleared and United States government-sponsored civilian scientists.

This center would also be the repository for the NTM ocean fiducial data, thus offering access to oceanographic capabilities for their intrinsic value as well as facilitating scientific exploitation of the NTM data.

This digital ocean data exploitation center would include capabilities to receive, store, and process large volumes of data; to decompress, format, enhance, and geolocate on demand; and to visualize and analyze the data on demand.

This center would eventually provide on-line connectivity to selected NAVOCEANO databases including those classified up to Sensitive Compartmented Information (SCI) levels. Access to the NAVOCEANO IDBMS and coregistration with the NTM ocean fiducial data are recommended. The georectification of the NTM data may not be applied routinely because of the large amount of processing required. It probably would only be conducted as part of a scientific analysis when required.

b. Regional Coastal Initiatives
Building on interest in littoral ocean areas, the Navy should expand its current efforts to build regional ocean models to include areas in proximity to the United States, possibly beginning with the Gulf of Mexico, which includes nearly all littoral types. If these models, and the fields used to initialize them, were made available, there would be considerable interest in the ocean science community. This would lead to active use, which would in turn generate feedback to the Navy, leading to improvements in the models.

c. IDBMS Connectivity

Wide access to IDBMS should be allowed. The IDBMS capability, when completed later this year, will represent a unique asset with no parallel in the civilian sector. Remote access to the classified version of IDBMS, with local exploitation through the exploitation center or via an encrypted link, should be arranged.

d. Network Accessability

On-line connectivity to databases approved for public release should be provided, thus vastly accelerating civilian use and generating feedback. It will probably be necessary to make provision for a "help desk" to address user issues.

e. Federal Ocean Science Agencies

The entire oceanography community would greatly benefit from a much stronger partnership among the United States government ocean science agencies (ONR, NOAA, NASA, DoE and NSF). In the past there has been more effective collaboration than at present, a situation which is clearly detrimental to all, particularly in an era of limited public funding for ocean science.

A significant step toward such an improvement in joint activities would be the implementation of the recommendations of this study. The civilian ocean science agencies would find that research efforts to exploit the Navy's environmental data holdings would become the focus of the improved partnership with the Navy. In turn, the Navy would find that the feedback received from close interactions with the civilian research community would lead to an evolutionary improvement in its own oceanographic capabilities. The exploitation center, in particular, would become a major source of collaborative energy in the ocean science community.

f. Visiting Personnel

Provision should be made for one or more visiting senior scientist positions at NAVOCEANO and for civilian participation in ocean surveys (with suitable restrictions regarding limits on release of any information obtained).

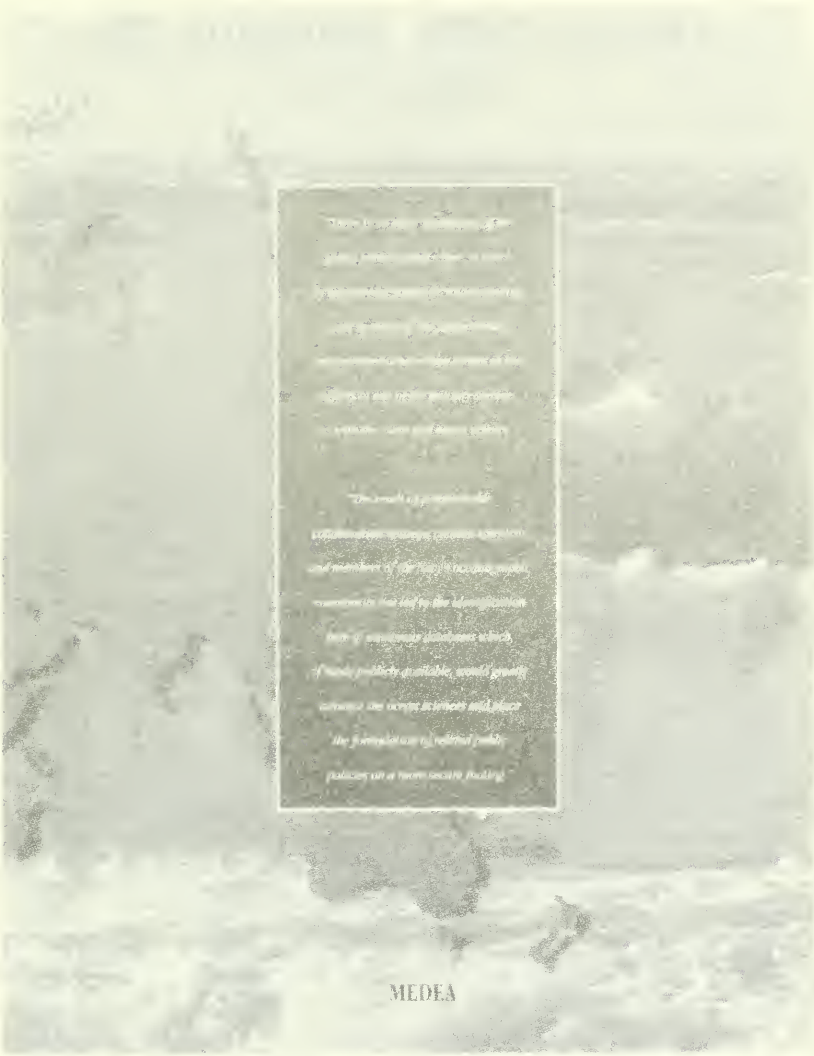
g. Overall

It is clear that a better understanding of Navy capabilities and problems by the non-Navy research community would lead to solutions of many problems. Encouraging researchers and students to address Navy issues by attracting them with access to data will accelerate all toward solutions for Navy problems. Clearly, a cadre of researchers would be spawned by the draw of accessible, interesting data.

GLOSSARY

Acronym	*Meaning*
ASW	Anti-Submarine Warfare
CEAS	Comprehensive Environmental Assessment System
CNO	Chief of Naval Operations
CRTF	Classification Review Task Force
DBDB	Digital Bathymetric Databases
DCI	Director of Central Intelligence
DIPS	Digital Ice Profiling System
DGPS	Differential GPS
DMSP	Defense Meteorological Satellite Program
DoC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DoI	Department of the Interior
DSDP	Deep-Sea Drilling Project
EO	Executive Order
ERS-1	Satellite that was launched by the European Space Agency
ETF	Environmental Task Force
FNMOC	Fleet Numerical Meteorology and Oceanography Center (NAVMETOCCOM)
FTP	File Transfer Protocol
GDEM	Generalized Digital Environmental Model
Geosat	Satellite that was launched by the U.S. Navy in March 1985
GIS	Graphical Information Systems
GM	Geodetic Mission
GOODS	Global Oceanographic Observation Data Set
GPS	Global Positioning System
GRASS	Geographic Resources Analysis Support System; an Army Corps of Engineers (USACERL) program that is used for geophysical databases/GIS
HSL	Hydrographic Survey Line
IDBMS	Integrated Database Management System
IGRF	International Geomagnetic Reference Field
IUSS	Integrated Undersea Surveillance System
LFBL	Low Frequency Bottom Loss
MC&G	Mapping, Charting, and Geodesy
MCSST	Multi Channel Sea Surface Temperature
METOC	Meteorology and Oceanography
MOODS	Master Oceanographic Observation Data Set

NASA	National Aeronautics and Space Administration
NAVMETOCCOM	Naval Meteorology and Oceanography Command
NAVOCEANO	Naval Oceanographic Office (NAVMETOCCOM)
NGDC	National Geophysical Data Center (NOAA)
NIC	National Ice Center (NAVMETOCCOM)
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center (NOAA)
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NTM	National Technical Means
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
PMEL	Pacific Marine Environmental Laboratory (NOAA)
ROV	Remotely Operated Vehicle
rms	root mean squared
SAR	Synthetic Aperture Radar
SASS	Sonar Array Survey System
SCI	Sensitive Compartmented Information
SeaBeam	Sea Beam Instruments, Inc., a manufacturer of survey sonar systems
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor
SECDEF	Secretary of Defense
SIMRAD	Manufacturer of ocean instruments
SSC	Stennis Space Center
SWDM	Shallow Water Data Model (GDEM)
Topex/Poseidon	Joint U. S / France satellite mission launched in 1972
ULS	Upward-Looking Sonar
USGS	U.S. Geological Survey
WMM	World Magnetic Model
WSC	Warfighting Support Center



[illegible]

"The results of [illegible]

[illegible]

and members of the [illegible]

community that led to the identification

body of government information which,

if made publicly available, would greatly

advance the ocean sciences and place

the formulation of related public

policies on a more secure footing."

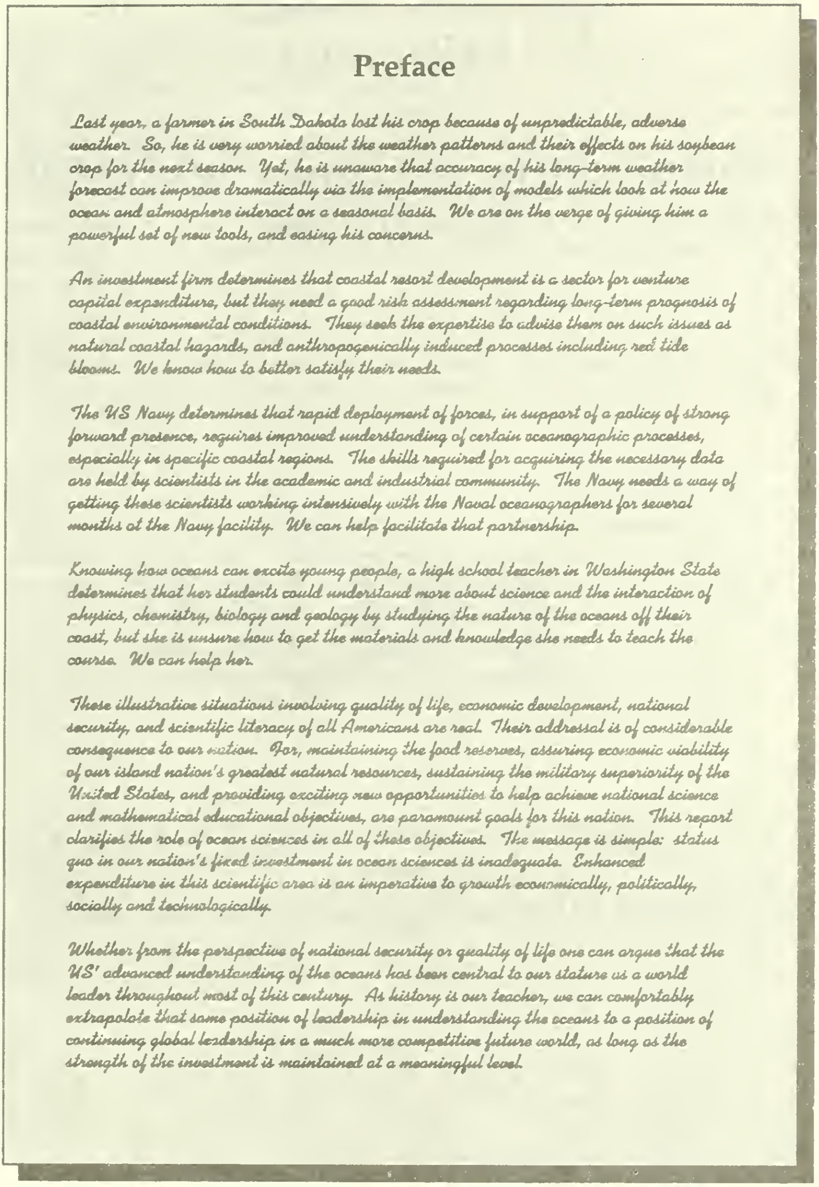
MEDEA

Oceans 2000: Bridging the Millennia

Partnerships for Stakeholders in the Oceans

CORE
Consortium for Oceanographic Research and Education

A Report on the Interagency Partnership Initiative
by the
Consortium for Oceanographic Research and Education (CORE)



Preface

Last year, a farmer in South Dakota lost his crop because of unpredictable, adverse weather. So, he is very worried about the weather patterns and their effects on his soybean crop for the next season. Yet, he is unaware that accuracy of his long-term weather forecast can improve dramatically via the implementation of models which look at how the ocean and atmosphere interact on a seasonal basis. We are on the verge of giving him a powerful set of new tools, and easing his concerns.

An investment firm determines that coastal resort development is a sector for venture capital expenditure, but they need a good risk assessment regarding long-term prognosis of coastal environmental conditions. They seek the expertise to advise them on such issues as natural coastal hazards, and anthropogenically induced processes including red tide blooms. We know how to better satisfy their needs.

The US Navy determines that rapid deployment of forces, in support of a policy of strong forward presence, requires improved understanding of certain oceanographic processes, especially in specific coastal regions. The skills required for acquiring the necessary data are held by scientists in the academic and industrial community. The Navy needs a way of getting these scientists working intensively with the Naval oceanographers for several months at the Navy facility. We can help facilitate that partnership.

Knowing how oceans can excite young people, a high school teacher in Washington State determines that her students could understand more about science and the interaction of physics, chemistry, biology and geology by studying the nature of the oceans off their coast, but she is unsure how to get the materials and knowledge she needs to teach the course. We can help her.

These illustrative situations involving quality of life, economic development, national security, and scientific literacy of all Americans are real. Their addressal is of considerable consequence to our nation. For, maintaining the food reserves, assuring economic viability of our island nation's greatest natural resources, sustaining the military superiority of the United States, and providing exciting new opportunities to help achieve national science and mathematical educational objectives, are paramount goals for this nation. This report clarifies the role of ocean sciences in all of these objectives. The message is simple: status quo in our nation's fixed investment in ocean sciences is inadequate. Enhanced expenditure in this scientific area is an imperative to growth economically, politically, socially and technologically.

Whether from the perspective of national security or quality of life one can argue that the US' advanced understanding of the oceans has been central to our stature as a world leader throughout most of this century. As history is our teacher, we can comfortably extrapolate that same position of leadership in understanding the oceans to a position of continuing global leadership in a much more competitive future world, as long as the strength of the investment is maintained at a meaningful level.

Oceans 2000: Bridging the Millennia

Partnerships for Stakeholders in the Oceans

CORE
Consortium for Oceanographic Research and Education

A Report on the Interagency Partnership Initiative
by the
Consortium for Oceanographic Research and Education (CORE)

Acknowledgments

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Considerable investments of time and effort were made by a large number of individuals. We are grateful to all participants in the Coordinating Group, the Steering Committee and the Working Groups. Without their contributions this project would not have progressed successfully. Special thanks go to the Chairs of each of the working groups: Mel Briscoe, Eric Hartwig, Len Pietrafesa and Dick Pittenger. Arthur Nowell's Chairmanship of the Steering Committee also deserves special mention. Additionally, John Delaney's activities early during the development of this initiative have proven valuable. We also thank Anita Whitney and Faye Brooks for providing much needed assistance and guidance in Seattle and Raleigh, respectively.

CORE staff deserve special thanks for their efforts. Chris Carmody, Johanna Pasquier, Marc Suddleson and Jamie Knox ensured that the working groups and the drafts of the report were completed in a timely and efficient manner. Valuable editorial comments and changes were made to the report by Terry Schaff and Lynne Claflin; their professionalism is evident in the quality of this report. Thanks also to Macy Moy for ensuring that all aspects of the activity were carried out in an efficient and effective manner.

We look forward to continued involvement by these and other highly regarded members of the ocean sciences community during future partnership activities.

Richard W. Spinrad

James D. Watkins

January 1996

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Executive Summary

Our national per capita investment in basic ocean sciences is a minuscule 4¢ *per week*! Yet - using research on El Niño as just one example - the American public has seen more than 100:1 return on its investment in this type of marine research. The successes of the past are the equity upon which future ocean science investments can be built.

In 1992 the National Academy of Sciences' Ocean Studies Board prepared a report entitled "Oceanography in the Next Decade," in which *new* partnerships were identified as the best mechanism to address a plethora of marine related opportunities and problems. The report contained herein builds on the work of the Ocean Studies Board, expanding the definition of the ocean sciences community to include academic, government and private sectors of research, development, applications, and education. This report is a statement of the most critical areas for development of new partnerships in US ocean science; the focus is on *how* ocean science needs to be done, rather than on *what* should be done.

The Consortium for Oceanographic Research and Education conducted this exercise at a particularly opportune time. Basic research is facing a requirement of increased accountability to society. The ocean science community, recognizing a need to meet this requirement directly, chose to take a proactive approach by redefining its efforts in a context of even greater relevance. In the past, ocean research applied mostly to national defense and a small class of commercial operations. Through the partnership initiative described in this report, the ocean sciences community has clarified the role their research will play in addressing an even broader set of societal issues and needs.

The ocean sciences community constructed this report with the support of several Federal agencies, and with the oversight of a Coordinating Group, including representatives of academia, government and industry. A Steering Committee, under charge of the Coordinating Group, identified the general societally-relevant themes of focus for this Interagency Partnership Initiative: Quality Of Life, Economic Development, National Security, and Education/Communication. Working Groups (in which more than 100 individuals participated) defined past partnerships and future opportunities for partnerships, within these thematic areas and consistent with the principles of partnership delineated in the recent report of the State-Federal Technology Partnership Task Force (1995).

The following are specific recommendations for three audiences: the researchers and educators, the executive agencies of government, and the US Congress.

Recommendations for researchers and educators

The reports from each of the working groups described a spectrum of specific opportunities for new partnerships, which all fell into three cynosural categories: *data, resources, and education.* Opportunities for new partnerships in ocean research and education are illustrated with selected specific examples as follows:

- Data
    - Declassification - *access to classified holdings*
    - Quality Control - *establishment of, and adherence to standards*
    - Long-Term Observations - *global ocean observing systems*
- Resources
    - People - *career development guidance and initiatives, personnel exchange programs*
    - Platforms - *construction of multipurpose oceanographic research facilities*
    - Computing - *centralized facilities coupled to data collection programs*
    - Labs/Infrastructure - *laboratory networks , sensor development consortia*
- Education
    - Formal Education - *pre-college teacher materials/curriculum development*
    - Informal Education - *marine information networks*

Recommendations for executive agencies of the government

The management plan contains the recommendations for government involvement. This report outlines the need for a management structure that sets up a highly visible National Ocean Leadership Council, consisting of the top officials responsible for oceanographic operations and research (Figure A). The Council would have a responsibility for coordinating and reporting to the Administration and the US Congress, the broad policy aspects of research efforts in ocean science currently being conducted and planned in the US. The concept of this Council is closely aligned with the thinking of the National Academy of Science in its recent report on "Allocating Federal Funds for Science and Technology." A Coordinating Group and Project Office, assigned to the National Ocean Leadership Council, will serve as the operational components within this management blueprint.

Recommendations for US Congress

> Finally, the report includes two specific recommendations involving the US Congress. These recommendations will identify mechanisms for Congressional facilitation and oversight of the management and conduct of the partnership initiatives. The report recommends legislation, specifically a National Ocean Partnership Act, including funding for putting the new partnerships in place. Additionally, the report identifies a congressional task force on ocean sciences as the locus for debate, communication and education of US legislators on marine issues.

Ocean science is an ideal forum for demonstrating the power of basic research to address the needs of society. The community of ocean researchers and educators is poised to begin a new era of partnerships in marine science. When fully implemented, the recommendations of this Interagency Partnership Initiative will propel the ocean science community forward, as was done a quarter century ago under the aegis of the Stratton Commission. The return on investment by society will be realized both immediately and well into the next millennium.

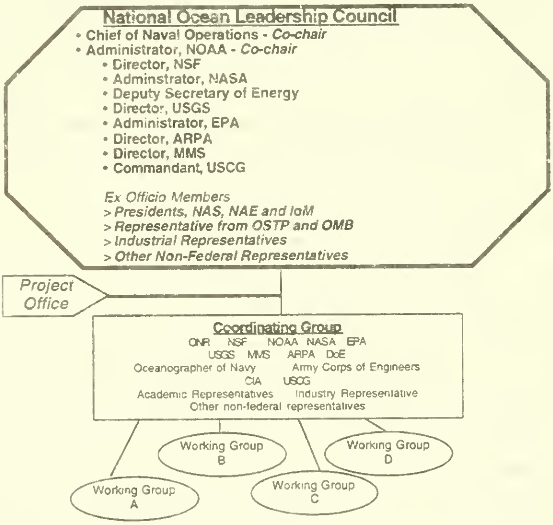

Figure A
Conceptual framework for National Ocean Leadership Council and supporting components

Introduction

The United States is an island nation whose history and future have depended upon and will continue to depend upon our leadership in understanding the factors controlling our environment. The environment is where we live, where we get our resources to live, and where we earn our keep. Our environment is controlled by the world's oceans. The oceanographic community owns skills which help define our nation's continued role as an international leader in the science of the oceans.

The majority of our country's states, 60%, have coastlines on the ocean or Great Lakes. Half of our population lives within the coastal zone. One out of every 6 jobs in the United States is marine-related. Yet less than 4% of the Federal basic research budget is spent on ocean sciences.

While the ocean sciences community is small (less than 2,500 Ph.D. level oceanographers are employed in US academia, government and the private sector ; NSF, 1991), the cadre of professionals in the field represents a wide spectrum of skills, from molecular biology to fluid dynamics to cybernetics to organic chemistry. The strength of this community has been based on two factors: its recognition of national research imperatives, and its capability to work cooperatively on scientific problems. In the chapters that follow there are examples of the well-coordinated efforts to transcend disciplinary and institutional boundaries.

The fact is, however, that the United States faces a new set of challenges in the next decade. These challenges demand all of the resources and capabilities of the ocean sciences community ... and then some! In the sectors of economic development, quality of life, national security and education the demands on society are being heard. Driving these demands are changes in global geopolitics, military requirements, technological capabilities, economic competition, international demographics and resource utilization. Recognizing the need to define general goals and in response to calls from the Ocean Studies Board of the National Academy of Sciences, the oceanographic community is drawing up the plans for addressing the new challenges. This document serves as a statement of the opportunities for partnerships in the future of oceanography in the next decade. With this statement, the community of ocean scientists is now poised to work toward meeting an even larger set of societal needs.

Background

In the 19th century, oceanography was placed in a position of high visibility by a Naval officer named Matthew Fontaine Maury. Maury, in service as the first Director of the Depot of Naval Charts and Instruments, recognized the value of standardizing the measurement of oceanographic properties, especially winds, currents and water depth. Maury knew that such measurements, while of obvious value to the Navy, were clearly useful to a diverse range of applications, including shipping, fishing and transportation.

Similarly, the bold model of public support for basic research developed by Vannevar Bush, subsequent to the end of World War II, ultimately demonstrated the rich return on federal investment of dollars in science and technology. This vision was the foundation for the highly efficient modern tools of public support for academic research programs, such as the Office of Naval Research and the National Science Foundation.

The Stratton Commission in 1969 extended many of these same concepts into defining a national imperative for supporting research and development in the marine environment. The outcome of that exercise was the establishment in 1970 of a highly visible National Oceanic and Atmospheric Administration (NOAA). The foresight of this visionary effort has been strengthened by the research over the last two decades. We now know that a focused research program including the interactive elements of oceanic and atmospheric dynamics is critical to addressing a wide range of society's needs.

Clearly, the main need addressed with the Federal investment in oceanography since World War II has been in the area of national defense. Basic research into the fundamental physical, chemical, biological and geological properties of the sea was successfully exploited during the Cold War. Our nation became a leader in the development of operational systems which could detect Soviet submarines, while conducting our own missions in a manner of lowest detectability. Such successes would have been impossible (and the consequences unimaginable) without the investments made possible by the visions of Bush and the Stratton Commission.

In the post-Vannevar Bush era of the late 1960s through the mid 1980s the Federal investment in basic research in the ocean sciences amounted to 7% of the Federal basic research budget. It was during this time that we developed the "tool kit" of skills that now allow us to:

- Predict El Niño and its devastating effects on regional climates and fisheries,
    - *through understanding the 'coupling', or connectivity between the ocean and atmosphere in terms of heat transfer, winds and currents*
- Maintain superiority in undersea surveillance and antisubmarine warfare,
    - *by virtue of knowledge gained from experiments in sound transmission through the ocean, allowing detection at longer distances, and lower sound levels*

- Provide the fundamental concepts related to the beginning of life forms on earth,
  - *via the use of manned and unmanned submersibles to study undersea volcanoes and their concomitant life forms*
- Save hundreds of thousands of lives through forecasts of coastal hazards (including tsunamis and hurricanes),
  - *made possible through the exploitation of high performance computing, allowing implementation of increasingly sophisticated, and accurate, models for forecasting coastal dynamics*
- Establish a whole industry based upon commercially viable fish farms and aquaculture facilities,
  - *through improvements in understanding of the physiology and ecology of important species, such as salmon and mussels*
- Locate and build oil platforms to maximize production and to survive the extremes of the ocean environment.
  - *as a consequence of new concepts in anti-fouling, ocean engineering, and seafloor mapping/characterization*

But where do we go from here? The 7% investment of the past gave us outstanding products. Clearly a stronger investment is needed for the broader set of challenges before us in the next millennium.

In 1992 the Ocean Studies Board of the National Research Council (NRC), recognizing the need to revisit the status, roles and plans of the oceanographic community, convened several meetings and prepared their assessment. Their report, entitled "Oceanography in the Next Decade: Building New Partnerships", has been a watershed event in the direction of this community. The objectives of the study were to "document and discuss important trends in the human, physical and fiscal resources available to oceanographers, ...to present the best assessment of scientific opportunities during the coming decade, ...and to provide a blueprint for more productive partnerships" (NRC, 1992).

The report of the National Research Council is particularly timely in that it deals with the redefinition of the oceanographic community in the context of society's changing needs. In opening remarks launching the National Research Council's report its Chairman, Dr. Frank Press, cited the marked changes taking place in this post-cold war period which seem to cry for new approaches to partnerships in the oceanographic scientific community. In fact, as he pointed out, "concerns about the ocean as a medium for warfare as a threat to national security are decreasing while environmental problems of the coastal zone and understanding how the ocean controls climate are of increasing importance." Further, he states that while "major advances in understanding the ocean in the development of technologies for observing it have set the stage for much greater research achievements," this comes at a time when "resources necessary to obtain this understanding are increasingly scarce." Hence, the Ocean Studies Board thought it important to undertake the study of where marine science found itself today and where it needed to head tomorrow.

The NRC report established a broad "framework in which improved partnerships ... can sustain the advances of the past, and lead our country and the world to greater understanding of the many roles the oceans play in human life."

Appropriately, the definition of a "partnership" in the current context is consistent with - but expanded upon, to include private sector interests - the definition provided by the NRC report:

"As the context in which oceanography is conducted changes, how can federal agencies, private industry, local jurisdictions, and oceanographers in academic institutions, government and the private sector[1] strengthen and improve their cooperative efforts? In general, partnerships must be extended beyond financial relationships to include the sharing of intellect, experience, data, instrument development, facilities and labor."

The proactive nature of such a proposed campaign is founded upon the recognition of certain trends and 'drivers' which point oceanographic researchers toward new areas of applicability. Some examples include:

Global environmental concerns
The Law of the Sea, the debates concerning sustainable development, as well as renewed interest in 'open ocean' resources (living and non-living), have put an emphasis on the careful use and understanding of the environment, including the 'Global Commons' (i.e. those ocean areas outside of the Exclusive Economic Zones of coastal nations).

Explosions in technology and communications
The ability to place highly sensitive instruments deep in the ocean, or far into space, with long-term monitoring potential has only recently become a reality. Similarly, high-speed, wide bandwidth data transmission now allows information and documentation to be sent to and from the most remote sites on Earth, with relative ease.

Restructuring of national security
Our nation's security demands diligent consideration to a diverse set of threats. Vulnerability includes our economic infrastructure and the communications networks upon which our society depends so critically.

National educational reform
A recognition of the need for systemic reform in our educational systems, from kindergarten through graduate school has developed rapidly since 1990. All levels are being rethought, with respect to curriculum reform, teacher enhancement, career guidance, integrated, constructivist and cooperative learning, as well as use of educational materials.

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[1] Underlined sections added here are not part of the NRC Report.

Society's Call to Action

It is in the foregoing context that, with multi-agency support, the ocean science and technology community, (represented by certain Federal agencies, academia, and industry), were brought together to establish a new and reinvigorated partnership concept. The idea was to lay the groundwork for carrying out the many challenges outlined within the framework of the NRC report where integration of more than one of these participating communities can add value to all connected partners and increase mission effectiveness and efficiency.

First, a Coordinating Group convened on July 27, 1994, in Washington, DC to provide some broad guidelines for a new partnership developmental effort. This Group consisted of eight federal agencies, two representatives of the academic institutions, and one marine industry advisor (See Appendix I for details). The Group concluded that before moving forward to establish the necessary scientific Steering Committee and workshops, the issues needed to be placed within a context enveloping traditional concerns of national security as well as the many rapidly emerging important social and environmental concerns such as environmental quality and economic competitiveness. These concerns are rapidly being accepted as harboring as much of a threat to our national interests in the foreseeable future as the threats of war.

The Coordinating Group believed that the subsequent outcome from both the Steering Committee and their follow-on working groups should show relevance to both changing national defense and sustainable national growth strategies in this post cold-war period.

To meet these objectives, the Coordinating Group set guidelines for Steering Committee make up and eventual report outcomes from the working groups.

The guidelines set for the Steering Committee were as follows:

A. To lay the baseline for working groups in the context of the general themes contained in the NRC report.

B. To develop an implementation plan including: (1) a prioritized list of themes and specific topics for consideration by the working groups deemed to be central to the development of an integrated ocean science and technology strategy; (2) an identification of team leaders and active participants for chairing and documenting activities of the working groups; and (3) a general format to be followed for reports of each working group.

C. To produce a comprehensive document, serving as the connective fabric for all of the working group reports, which would be used by a range of audiences associated with development and implementation of policy in ocean science and technology

The Partnership Steering Committee then met for two days, October 27-28, 1994 to develop specific guidance for working groups in the development of an integrated implementation plan for ocean science and technology wherein partnerships could play an effective role. This Committee consisted of 27 members: eleven representing Federal agencies, eleven representing academia, four from the marine industry, and the President of CORE (see Appendix II for membership details).

The Steering Committee believed that a broad thematic approach should be taken, invoking themes of a nature highly relevant to society's needs. Four themes associated with our national interests, and, hence, four working groups were suggested. These are listed below and broadly defined as indicated.

1. National Security - Ensuring that national interests are guaranteed at home and abroad and that basic and applied ocean science remains an essential element of this assurance. This category is meant to include issues associated with preservation of our national interests, via military defense, and foreign policy support.

2. Economic Development - Use of the basic and applied knowledge of the ocean and its resources for economic gain, including attention to marine resources, transportation, recreation, development, and related industries.

3. Quality of Life - Health and social well-being of people as derived from using basic and applied knowledge of the ocean. Subject material includes the topics of preservation/improvement/ stewardship of the environment (pollution prevention, cleanup and remediation), shoreline protection, coastal hazard mitigation and recreation.

4. Communication/Education - Conveying an understanding of the importance of oceans to national decision making, to the public at large, and to decision makers and educators at every level using basic and applied knowledge of the oceans, to include the exploitation of state of the art electronic networking and computer based simulations/ demonstrations.

During the summer of 1995 four working groups were convened. Approximately 100 professionals from academia, government and the private sector met to discuss the role of ocean sciences in these respective areas (See Appendix III for membership details). The groups worked toward several very specific objectives:

- Identify the driving forces behind the new challenges to ocean sciences in each thematic area.
- Define those partnerships which have been undertaken in ocean sciences in the past in each thematic area.
- Identify future opportunities in ocean sciences relevant to the thematic area, and specify those best suited to a partnership approach.
- Indicate the characteristics unique to a partnership in this particular thematic area in ocean sciences.

Past Partnerships - Principles and Oceanographic Experience

WHY PARTNERSHIPS:

Partnerships are a valuable tool for exploiting distributed capabilities and resources. In essence, the set of issues which the oceanographic community is bracing to address are enormous by any dimension: the volume of data, the geographic breadth of impact, the range of disciplines, the variety of assets, and the physical challenges. A characteristic issue faced by this small but diverse community of scientists is that the expertise is distributed throughout the nation. The breadth of skills required in oceanography, coupled with the relatively small number of skilled practitioners translates to a thin, but wide distribution of capabilities. The situation might be compared to having a different medical specialist located at each hospital throughout the country: all of the necessary skills are at hand, but they are widely distributed. This condition is dramatically compounded by the high level of sophistication and multiple, costly platforms needed to make measurements or predictions in the ocean environment. Many of the major resources (people, equipment, platforms) are one-of-a-kind, resulting in a de facto establishment of many centers of excellence for the field. By fostering the development of new partnerships we can overcome many of these apparent obstacles. Through sharing of resources, data, and knowledge the ocean sciences community will provide an impressive machine for working towards solutions.

The partnership-based solutions provided by the working groups are not aimed at redefining national priorities for research in the marine environment. ***The question is not 'What should be done', but, rather, 'How should it be done'.*** These concepts were developed with the goal of optimizing the performance of the oceanographic community, with the payoff being the enhancement of the US national interests. It is also noteworthy that the emphasis is not on the concept of partnerships, since such a concept is hardly new. Instead, the emphasis is on which NEW partnerships are needed and how they can best be constructed.

In a related effort of the State-Federal Technology Partnership Task Force (chaired by Govs. Richard Celeste and Dick Thornburgh in collaboration with the Carnegie Commission on Science, Technology and Government, the National Governor's Association, The American Society of Mechanical Engineers, The White House Office of Science and Technology Policy, and the National Conference of State Legislatures) a very thoughtful definition of the principles of successful partnerships has been provided. These principles (which are categorized as "Overarching Principles" and "Operational Principles") are cited here; clearly the oceanographic community has a rich heritage of partnering which adheres to these fundamental concepts.

OVERARCHING PRINCIPLES OF PARTNERSHIPS

(from The State-Federal Technology Partnerships Task Force Final Report, 1995)

Shared Ownership *- "The success of a ... partnership depends largely on each participant's long-term commitment to, and sense of ownership in, the objectives of the venture, and an acceptance by each of the shared responsibility necessary for achieving mutually acceptable outcomes"*

The Eddy Joint Industry Project (EJIP) (Appendix IV.A.) was an example of this concept of shared ownership. In this case the federal government and oil industries saw the benefit of sharing facilities and contributing their assets to a set of objectives meeting each party's mission. Notably, each of the participants had their own specific set of objectives. The merit of the partnership lay in the sharing of assets and the mutually acceptable approaches.

Broad Participation / Diversity of Interests *- "A partnership is enriched, and the likelihood of success improved, by broad representation of the interested parties in its design and implementation."*

Many examples of this kind of partnership exist within the oceanographic community. Two vastly different case studies are the MEDEA project (Appendix IV.B.) and the World of Water Program (Appendix IV.C.). In the first case, which was a partnership of fixed and limited duration, the participation included a broad base of academic researchers, industry representatives and members of the research and operational components of the US Navy. In fact, one could argue that the impetus for this activity was in the breadth of potential interests. The World of Water Program included a diversity of interests as represented by the participation of state government, non-profit organizations, academia and the private sector.

Champions / Advocates *- "A successful ... partnership requires the demonstrated personal commitment of senior ... leaders"*

Some of the most successful partnerships in oceanographic education have been those directly involving some highly visible individuals. One case in point is the JASON Project (Appendix IV.D.). In this case, one scientist of celebrity status, Dr. Robert Ballard, has been a persistent motivating force in the evolution of this program. The result has been a dramatically increased awareness of marine issues by a huge audience of students. His partnering with prominent industrial champions has been an element of the success of this partnership.

By the same token a classic example of a partnership which did not succeed due to a lack of demonstrated commitment of senior leaders was the Institute of Naval Oceanography (Appendix IV.E.). In this case, other principles for partnering were upheld (e.g. shared ownership) but the apparent lack of champions served as a fatal flaw.

OPERATIONAL PRINCIPLES OF PARTNERSHIPS (ibid.)

Partnership Formalization *- " To avoid misunderstanding and to protect the interests of all participants, partners should define each partnership formally, in writing."*

An outstanding and enduring example of this principle of formalism is the National Ice Center (NIC) (Appendix IV.F.). In this case, Federal agencies exclusively, have established the philosophy and process for managing a critical marine operation. From the beginning, the formal establishment and documentation of NIC was recognized by all parties as critical to its survival and success.

Merit-Based Decisions *- "Creating new models of ... partnerships capable of responding effectively to a changing science and technology environment requires that resources be allocated on the basis of which partner or interested party can best perform the task at hand.. Scarce resources must be applied where they are most likely to produce the greatest return on public investments and the broadest-based benefits."*

The example of state-Federal-academic partnership embodied by the Sea Grant College Program (Appendix IV.G.) demonstrates the effectiveness of technical review and merit-based decisions. The definition of "merit", which is contentious, must be clear from the start. In the case of Sea Grant, merit is determined on the basis of technical quality of proposed research, as well as relevance to the palette of NOAA missions.

Flexibility *- "Flexibility, within general guidelines to ensure accountability is needed to foster experimentation and innovation."*

Oceanography, by virtue of being a relatively new and young field, must be characterized by flexible approaches. In terms of oceanographic partnerships this flexibility to continuously fold in new partners is demonstrated very effectively in a new partnership of academia and industry (sponsored by the Federal government) in the Ocean Technology Center at the University of Rhode Island (Appendix IV.H.). The concept of flexibility as a principle of partnerships is especially important for ocean sciences now, when the community is starting to adapt its research to a new range of applications.

Cost-Sharing *- "Partnerships are more effective when each individual partner has a financial investment*[1] *in the conduct and outcome of the program."*

Within the educational arena of oceanography there has long been recognition that the missions of many agencies can be supported with educational campaigns. Nonetheless there are only a few examples of educational partnerships in which there is substantive cost-sharing. One highly successful example of cost-sharing by multiple government agencies is the program entitled "Operation Pathfinder" (Appendix IV.I.). Interestingly, this particular partnership, in which NOAA, the US Navy and the Department of the Interior share all costs, is also a good example of the principle of diversity of interests.

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[1] Investment is assumed to include in-kind costs, such as waived overhead costs or contribution of labor.

***Evaluation** - "At the beginning of a project, partners must agree on the partnership's goals and objective, operational elements, and the methodology for measuring both progress and outcomes."*

There are large expenses and intricate scheduling difficulties associated with management of the oceanographic research fleet, which is mostly owned by the Federal government and operated by the academic research community. Consequently, the management partnership which has been established is predicated on clearly stated goals and objectives. This partnership, the University National Oceanographic Laboratory System (UNOLS, Appendix IV.J.), has worked quite efficiently for many years. The additional value of the UNOLS partnership is that its philosophy, structure and process are well-enough established (in terms of evaluation mechanisms) that it is easily adaptable, thus adhering to the operational principle of "flexibility" to the growing suite of research platforms (e.g. aircraft and buoys).

The requirement for having a "methodology for measuring both progress and outcomes" is one which is central to the recommendation below, in the management blueprint.

***Stability / Long-Term Commitment** - "The partners' long-term commitment to the partnership is vital to success."*

Some problems, especially in the environmental arena, can only be solved with long time-series of data. Because of the costs associated with acquiring data in the field, this kind of commitment can be difficult to maintain. The California Cooperative Oceanic Fisheries Investigations (CalCOFI, Appendix IV.K.) is an excellent example of a multi-decadal partnership. This partnership has also demonstrated the collateral benefits of this type of stable and long term commitment, as the research results, which were originally obtained for analysis of California fisheries are now proving invaluable in much of the discussion regarding global climate change. An additional aspect of CalCOFI has been its durability: it has been flexible enough to operate with a wide variety of support bases over the years.

NEW PARTNERSHIP OPPORTUNITIES

There is a very broad realm of research opportunities defined by the diversity of issues embedded in the subjects of quality of life, economic development, education/ communication and national security. Nonetheless, it is quite noteworthy that for the purposes of defining partnerships, several consistent themes emerged from the deliberations of these distinct working groups. The pervasive nature of these themes lends strong credibility to the partnership approach; there is an implication that a partnership developed to address a problem in one area will provide collateral benefits to other applications.

What follows is a description of the opportunities for development of specific partnerships in oceanography. The intent is to identify where the key target areas exist and what the specific focus of partnerships should be to address the most urgent community needs.

Data

DECLASSIFICATION - The currency of oceanographic progress is data. The ocean environment is largely undersampled or unsampled. There exist data which might serve multiple needs. Many of these data, however, are kept under lock and key, and their access is restricted for purposes of national security. A recent exercise, entitled MEDEA has demonstrated the value of many of the classified oceanographic data, for application to a wide range of problems including global climate change, earthquake studies, and biological productivity of the oceans, with no concomitant threat of reduced security.

Subject: Data Accessibility

Background: The Navy holds in its operational database vast quantities of information collected at great expense over decades. One will not be able to collect such a data set again. Some of the data are unclassified and prospects for more of it to be declassified are promising. The Navy also regularly models its data for analysis and prediction. These too are such sources of information. Finally, the Navy has invested in an Integrated Data Base Management System (IDBMS) which is an information discovery and management tool that provides for georeference and inter-related data. There is probably no better collection of global ocean data more readily usable or electronically reachable.

Opportunity: Remote access to these valuable unclassified data sets using state-of-the-networking-art on-line connectivity facilitated by IDBMS data management systems. This opportunity may be extended to all civilian users when unclassified data are involved, but policy questions will need resolution first.

Hurdles:

1. Cost: While not significant, there are some costs in the $2-4 M (estimated) range to procure networking hardware, to install precautions against inadvertent release of classified data or model information, and to manage the networking system.

2. Policy: For decades, all unclassified oceanographic data went to national data centers for further archiving and distribution. Building on the modern trend of distributed archives and database management may mean new or additional routes to important oceanic data. Moving from central national archives to direct access of Navy data by authorized users need not be threatening to existing centers. While this initiative should neither be a hurdle or a threat, it will need to be discussed. Data should continue to be made available to the national archival centers, perhaps using the same on-line data transfer techniques.

Rationale for Partnership: On-line connectivity between the Navy's oceanographic data/model sources and available users can accelerate and expand civilian and commercial use of unclassified high quality data. Feedback to the Navy will result as surely as civilian and commercial successes will. Further, one would expect a return of civilian data and commercial products to the Navy for inclusion in Navy managed database/models. Also, such capabilities would undoubtedly make US companies more competitive in foreign markets.

Expected Product: An on-line connectivity linking Naval oceanographic and civilian oceanographic government, industry, and academic organizations for the purpose of quality data transfer.

LONG TERM OBSERVATIONS - For the same reasons that the land-based weather forecasters depend on distributed networks of observational systems, the oceanographic community needs these capabilities. In fact, one of the most dramatic demonstrations of the value of long-term observations is the payoff from the TOGA (Tropical Ocean - Global Atmosphere) buoys in the central Pacific ocean. This system has served as the primary early warning system for El Niño onset in the last decade. As a result we now have vastly improved capabilities for long-term forecasts. The investment and commitment needed for such an effort, however, are serious and large.

Subject: US Contributions to a Global Ocean Observing System (GOOS)

Background: The ocean (both deep and coastal) is a highly dynamic environmental system whose space/time variability is of the same general order as the atmosphere in part due to the coupling of two systems. In contrast to meteorology, there is no equivalent coherent synoptic monitoring and prediction technology for the oceans. Different agencies collect partial data sets or provide rudimentary predictions; but the effort is significantly below what is required. The data sets on waves, tides, circulation, temperature, salinity, and biological indicators are of potential use to governments and private industries concerned with hazard protection, transportation, recreational and environmental planning. The feedback of the oceanographic information to atmospheric models should eventually improve weather forecasts as well. Coastal regions worldwide are susceptible to heavy damage from earthquakes, hurricanes, storms and flooding. Hurricane damage on the east coast of the United States and the recent earthquake in California have resulted in a collective billion dollars worth of property damage and loss of commercial revenue. Several atmospheric and land-based observation programs exist currently which are dedicated towards sensing the formation of tropical storms and recording seismic events along the California coast, additional information can be gained from ocean bottom and ocean surface deployed sensors which when combined with the currently available data would greatly enhance the understanding of these destructive events and provide new capabilities for disaster prediction throughout the globe. Bringing this all together and providing a mechanism for development and coordination is the task of GOOS, an intergovernmental program under the sponsorship of several international agencies. The goal of GOOS is observations to aid the public good, by making use of past research results, motivating new research, and maintaining operational observational programs. The US contribution to GOOS is currently built around an Interagency Working Group with representation from NOAA, NASA, NSF, Navy, State, Interior, Coast Guard, EPA and DOE, with scientific review from a GOOS panel of the NAS/NRC.

Opportunity:

(1) US GOOS currently sets priorities and determines content on the basis of individual agency contribution; the opportunity for joint development of activities that no one agency could tackle alone has not been exploited.

(2) Academic input to the US GOOS is primarily through the NAS/NRC GOOS panel. This could be made more significant and have more impact if there were several continuous academic working groups addressing scientific aspects of the five modules of GOOS (climate, Health of the Ocean, Living Marine Resources, Coastal Zone, and Marine Services).

(3) Industry has two major interests in GOOS, namely as a supplier of GOOS equipment and data/products, and as a user of the output of GOOS, for example for improved ship routing. Neither of these interests is being fully exploited, which suggests a wider partnership that includes industry more explicitly.

Hurdles: More communication and outreach is needed by US GOOS to enable its constituents to develop and be nurtured, which requires funding. In the current climate of reduced funding, it is more important to improve our mechanisms for working together, but scientists, agencies, and industries are finding it difficult to watch the horizon and take the long view. The development of a GOOS System would require overcoming four important hurdles:

1. The scientific determination of the proper parameters to measure, the correct instruments, and optimum locations for deployment.
2. The design and manufacture of precise, reliable components and data links
3. The logistics of installation of the systems
4. The establishment of data recording, storage, analysis and distribution facilities.

Rationale for Partnership: GOOS, and its objectives , are too big for any single group to address. Partnerships are essential to bring the required interests, tools, and users together. The users are a critical part of the partnership, and, in light of the recommended partnership dealing with declassification, it could be suggested that incorporation of such capabilities into GOOS would be of benefit to our national security as well.

Expected Product: A stronger constituency for practical oceanography, encompassing many specific tasks involving data and observations. At least daily observations, predictions of ocean physical parameters (waves, tides, surges, currents, temperature and salinity) along with biological parameters such as color. Coherent databases of the observations or assimilated fields can be developed to provide equivalents to meteorological climatologies. The ultimate products are oceanographic analogs to the information now provided for the atmosphere.

QUALITY CONTROL - One of the major advances to ocean science was made in the mid-1800s when Matthew Fontaine Maury standardized the methods for collecting data at sea. Today, because of the rapid advances being made in sensing technologies, and the capabilities to put data and information easily into the public access, the oceanographic community runs the risk of major problems with quality of data. Access to an information highway that contains raw, unverified, often sensationalized data can be a great danger to both the decision-making and scientific processes. We need to invoke standards, as Maury did, and establish protocols for introducing data into the public domain. Clearinghouses, industry standards and community stewardship are the tools that must be established.

Subject: National Ocean Observation Quality Assurance Initiative

Background: This partnership would provide a comprehensive scheme for data quality assurance throughout the anticipated major information pathways to be developed in the future, (e.g. the Global Ocean Observing System, GOOS). The scheme would build on and supercede smaller prototype efforts in the current Integrated Global Ocean Services System (IGOSS).

Opportunity: Future observational networks in the ocean are anticipated to consist of enhanced measurement, modelling, and delivery systems; for a host of critical ecosystem measures and standard physical parameters. Because the expected information management methods will rely heavily on Internet traffic, and because a large number of participants will not be performing as "contractors", measures to instill strict data quality assurance will necessarily rely on voluntary means. It is likely that a rigorous program of certification, based on community agreement to a range of qualification procedures (e.g. comparison with climatology), can be implemented successfully. Participation in certification efforts can become strong bonds within growing Federal-Academic-Industry partnerships.

Hurdle: The process of identifying appropriate certification procedures and in gaining community acceptance will require a lengthy community dialogue.

Rationale for Partnership: Global observational programs will fail utterly without full participation by the above segments of the ocean community; this proposed certification process will likewise require a partnership.

Expected Product. Community accepted protocols and standards, used by all participants in the identification, collection and dissemination of data and information.

Resources

PEOPLE - Clearly the most valuable resource in oceanography is the cadre of trained professionals and capable students working in the field. The future body of researchers and educators in the ocean sciences may be distributed among a broader range of careers and job sectors than are currently represented. Efforts are already underway to develop mechanisms to train the next generation of ocean scientists in fields such as business, public policy and communications, in order to expand the involvement of the oceanographic community. The current number of oceanographers suggests a need for partnership initiatives aimed at distributing the capabilities, sharing this resource, and ensuring some quality control on the level of expertise. The community should establish formal mechanisms for facilitating the exchange of personnel between academic, government and private organizations. Some mechanisms for these exchanges currently exist, but they are cumbersome and more prohibitive than conducive to cooperation. Additionally, a partnership approach might be invoked to assess the value and implementation of a professional certification program, as is done in many other technical fields.

Subject: Internships and Personnel Exchanges: Government/Academia/Industry Cooperative Human Resource Utilization

Background: Crosstalk and mutual understanding of goals among mission agencies, academia, industry, research agencies, and policy makers are deteriorating to an all time low. This comes at a time when downward budget pressures call for "downsizing" mission "purification" and "deregulation." These two groups of trends combine to be very counterproductive, and are exacerbated by significant mission/interest shifts on the part of several agencies. Crosstalk and mutual understanding must be fostered at all levels from program execution to planning and setting of national policy.

In addition, certain private industries have operations that are synergistic with the education of students in the oceanographic community. Oceanographers from academia could benefit from opportunities to work in industry, to be exposed to the needs of industry, to apply data being generated in the research environment. Programs could be set up to support such cooperative efforts.

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Opportunity: Mechanisms, in addition to the traditional Intergovernmental Personnel Act, must be developed to encourage cross-fertilization as described above. Examples include:

- visiting senior scientists to operators and to policy making organizations,
- participation of industry and other user-community representatives across agency planning and policy lines,
- graduate education, research sabbatical and industry/laboratory appointments for military, government, and policy employees.

These mechanisms should span from short term exchanges to long term appointments. In view of the Info Highway/WWWeb, it may be feasible to create "virtual appointments" that may also include "video conferencing and meetings."

Hurdles: The primary hurdle is, of course, availability of manpower and the low priority often assigned to these activities. A subtle problem is the increasing restrictions placed upon the exchanges by unreasonable application\interpretation of conflict-of-interest regulations.

Rationale for Partnership: A partnership would enhance the value of any data being collected, add to the experience base of the participants thereby making them more effective, and providing all sectors with a resource base that was not available to date. All participants could reduce costs for performing oceanographic related tasks, through a reduction in the full-time equivalent positions employed.

Expected Product: Better understanding of both common and unique issues as well as a basis for improved communications between participants. For the oceanographic research community in government and academia, an opportunity for some to experience industry - its operations and the application of oceanographic data, enhancing the value of the data being collected by applying it in new way. For industry - the resource of an experienced individual (an expert at times) in an application where such "short term" expertise is necessary would be a valuable asset to the operation.

Subject: Certification of oceanographers

Background: Traditionally, accomplishment of advanced training in the ocean sciences has been evidenced by Masters and Doctoral degrees. Because oceanography is inherently multi-disciplinary, and because degree requirements vary among institutions, attainment of a graduate degree does not necessarily indicate that degree-holding individuals possess a common set of skills. For purposes of employment of ocean scientists in non-academic careers, it may be desirable to establish a certification program for oceanographers. The professional certification program for meteorologists may serve a successful model on which the ocean science community can build.

Opportunity: Taking into consideration potential employment opportunities for trained ocean scientists (e.g. in media, education, industry, politics, law) partnerships to establish certification criteria should be formed. Partners could include research institutions, professional societies, industry and government agencies. Criteria would reflect standards set by the ocean science community as well as the needs of potential employers. It may be that multiple types of certification are appropriate. These could emphasize particular skills such as communication, computer science, instrument development or knowledge of the legal system. Earning certification in ocean science may require training that differs from the curricula currently followed by oceanographic institutions. Offering ocean scientists-in-training the opportunity to prepare themselves for non-academic careers, and setting standards for certification would serve both the academic community, private industry, and society in general.

Hurdles: Potentially there will be resistance to proposed certification within the academic community. The reasons for resistance will need to be identified and addressed. It may not be necessary or even desirable for all oceanographic institutions to offer certification programs. However for the certification program to be successful, some agreement as to its meaning and value must be reached within the ocean science community. For an ocean science certificate to be useful, there must be jobs for which the certificate is required. At present, the bulk of jobs available to oceanographers exist within academic institutions, with smaller numbers of positions existing in government agencies. A market for certified ocean scientists must be established within the private sector.

Rationale for Partnership: Certification criteria will reflect standards set by the academic ocean science community and the needs of potential employers, hence partnership is critical to the success of a certification program.

Expected Products: As a source of knowledge and skills, certified ocean scientists will help meet society's needs for information about the ocean. Certification will allow the academic community to set and uphold standards that will reflect positively on the research community. Organization of a certification program will bring together the oceanographic community in an unprecedented way, perhaps stimulating re-evaluation of graduate programs and realignment of priorities to benefit both the academic community and society at large.

PLATFORMS - The oceanographic community is a research platform - intensive group. Unlike many other scientific arenas, the oceanographic field critically depends on efficient community management of surface ships, manned submersibles, autonomous underwater vehicles, scientific buoys, and research satellites. Plans for future field work will add capabilities to this list (e.g. ocean sampling networks, global observation systems) making the management of these research platforms an even more challenging endeavor. Partnerships are critical for successful application of these facilities.

Subject: Offshore Construction of Multi-Purpose Platforms

Background: The US continues to experience a population increase, particularly in regions concentrated near the coasts where 50% of the population now resides. As coastal regions become ever more crowded, the idea of building structures offshore for a variety of purposes becomes more attractive. Offshore airports have already been constructed in Japan and are rapidly gaining appeal here for both land use and noise mitigation purposes. Artificial harbors which can accommodate larger, deeper-draft vessels would make international shipping safer and more accessible. Megaplatforms for offshore oil production and development would house families of support personnel as well as schools, churches, food stores and whatever else is needed to support an entire offshore community. Purely recreational offshore travel destinations are also possible with hotels, theme parks, restaurants, and casinos. In some cases, offshore highways could be built to reach them. A wide variety of structures is possible, ranging from artificial islands to bottom-mounted and semi-submersible platforms.

Opportunity: Innovative materials which are becoming available now make these new structures possible. Carbon fiber and composite plastics could be utilized for strength, light weight, low manufacturing costs, and resistance to corrosion and biofouling. Other construction methods include re-use and re-combination of existing offshore structures from the oil industry, and recycling of dredged materials from the ocean and solid waste materials from the land (fly ash, sanitized sludge, etc.) to form artificial islands offshore.

Hurdles: The technology necessary to develop these large offshore structures in a cost-effective manner is presently being developed. The federal regulations regarding environmental impacts of these structures would be enormous.

Rationale for Partnership: Partnerships are required between government, industry, and academia to conduct the necessary environmental impact studies. These would include impacts on the coastal circulation and sediment transport, positive and negative impacts on the local biota, visual impacts, and hazards to navigation. AUVs and robotic systems would be needed during the construction and maintenance of some structures. Offshore structures provide platforms for mounting instrumentation for research, weather prediction, and aquaculture. The physical size and magnitude of the proposed projects cross state lines and demand partnerships for successful financing and completion.

Expected Product: The expected products are innovative offshore structures which can replace or improve upon facilities traditionally housed near the coasts, being used by the layman and the research community alike.

COMPUTING - One of the major accomplishments of the oceanographic community in the last decade has been associated with advances in 'data assimilation', the capability of upgrading a predictive model by incorporating data on a regular basis. Advanced development of state-of-the-art massively parallel computers progresses. Scientists will continue to recognize the advanced capabilities of these machines, and teachers will utilize their sophisticated programs for visualization and simulation. The costs of these computational systems are high and their access is limited. Careful partnering between the owners, operators, programmers and analysts is essential, and coupling these efforts with the data collection partnerships, described above, will be highly productive.

Subject: Operational Ocean Characterization System

Background: The Navy, for national defense purposes, and civilian organizations, for scientific purposes, require the capability to measure, analyze, and predict the state of the world's oceans on a continual basis. Such a continuum of function calls for fusion of data previously collected with that being collected (e.g. via GOOS as described above), developing an analysis of current oceanic conditions using numerical models based on best physical principles understood, and finally, using best predictive model techniques, forecasting of future oceanic conditions. An operational system that leaves out any part is less useful and does not effectively utilize the resources at hand.

Observational strategies and operations are improved by concomitant "end-to-end simulation" or "model-mediated approaches." This optimizes the data gathering methods against the underlying requirements, as well as the relevant physics and processes. Techniques that not only adapt to the incoming data stream but also alternative sources of information (e.g. remote sensing) offer a major capability enhancement.

Opportunity: The ability to assimilate significant amounts of disparate data in real-time and onscene together with very capable but relatively inexpensive numerical processing machines make a "model-mediated" approach very possible in the near to midterm (3-5 years). An opportunity exists to forge partnerships which bring together archival and near real-time collected data, large-scale computational facilities, predictive models and the methods to distribute results for operational purposes and correction of/improvements to the operational oceanography system.

Hurdles:

1. Multi-agency commitment for the long term. It is an infrastructure investment.
2. Tendency to stop at collection/archival thereby preventing fullest utility and modeling feedback/improvement.
3. Bringing all assets to bear (e.g. GOOS, satellites [multi-sensor], IUSS, supercomputers, models).

Rationale for Partnership: In addition to savings due to mutual leveraging, there is an overall advantage that stems from a common basis for survey strategies. This will lead to improved understanding of survey results as well as more commonality of formats and higher quality standards. Several agencies and civilian talent need to be posted to make the initiative sufficiently solid and then sustain it.

Expected Product: An archive, both historical and current; a modeled analysis of current/near current ocean conditions; a prediction of oceanic conditions. In addition to the above "survey multipliers", the overall approach leads to a robust nowcast capability which has value in its own right.

LABS / INFRASTRUCTURE - Laboratories and the collection of facilities that comprise the infrastructure of oceanography (e.g. large systems of instrumentation, such as ocean bottom seismometers) are as unique to the field as the research platforms. Again, the diversity of the field has been translated into specific technical strengths at individual laboratories. The US Navy has particular capabilities for acoustic studies, for example, whereas the expertise for developing open ocean buoys resides at only a handful of academic and federal laboratories. The optimal exploitation of these facilities can only be attained through a program of sustained and active partnerships between the institutions.

Subject: Marine Laboratory Networks and Natural Laboratories

Background: Growing national security and other US interests in littoral regions together with an emerging S&T capability to adequately address this complex environment, offers an opportunity for interagency partnerships to establish a portfolio of coastal natural laboratories. These would be visited regularly to provide baseline data to understand processes, validate models and algorithms, and to test operational products across the various agencies and participating industry. In this way, a positive feedback of engineering models to fundamental physics and process studies can be used to shorten product development time as well as fidelity/skill. Carefully chosen locations can also serve as ground-truth for remote sensing (acoustic, space, and airborne techniques) and should be co-located with fiducial sites wherever possible. Notably, the world's marine laboratories are the repositories of collections and historical data of critical importance for coastal research. They have facilities to provide access to marine habitats, institutional stability , and history of working together. The US National Association of Marine Laboratories is developing a network of US marine laboratories. The terrestrial LTER (long-term ecosystem research) network provides a parallel example.

Opportunity: A specific opportunity exists, for example, to study biological diversity on a regional scale (the need for regional scale is emphasized in the recent NRC Report, Understanding Marine Biodiversity) and in a sustained way, e.g. long-term. Habitats would include estuaries (watershed to the coastal ocean), rocky shores, coral reefs, and continental shelves.

Hurdles: None that are significant, however some agencies may need to be coaxed. Agreement will be needed among laboratories and participants on common measurements.

Rationale for Partnership: Primary driver is mutual leveraging to bring sufficient resources (intellectual as well as fiscal) to bear. The urgency of issues such as loss of biodiversity demand a focussed and concerted effort, only attainable through partnerships.

Expected Product: Well founded and common basis for algorithms, models, policy and decision aids and sensor performances across US agency mission areas. Not only does this leveraging reduce the costs of gaining these capabilities, but will also reduce costs in the utilization of the knowledge gained.

Subject: Oceanographic Sensor Communications

Background: Most of the past oceanographic measurements were taken from ships or moored buoys, and these data have formed the data bases upon which the US government produces its predictions of weather and sonar system performance. It is now evident that many important oceanographic processes are undersampled both temporally and spatially and that there are not enough ships and buoys for accurate models. This has led, especially with the advances in microchip electronics, to remote instrumentation to acquire these data. One of the major problems is that it is often very difficult to transfer these data from instrument to the user. There are basically two approaches: i) transmitting the data by means of a cable, now usually fiber optical and ii) telemetering the data through the ocean surface and then a satellite link to the user. Cables are expensive to install especially in the deep ocean while telemetering and satellite links have very limited bandwidths. The most common means is by the French ARGOS system which has very limited bandwidth and is approaching saturation in some regions. Currently, communicating with oceanographic sensors, especially those in the deep sea at long ranges, is often the limiting technology in their use.

Opportunity: Several options for high data rate communications need to be developed which make data transfer reliable and inexpensive. This would permit obtaining denser and more frequent data for scientific use, commercial applications, and Navy predictions.

Hurdles: There are several technological hurdles. While optical cables can be placed for long distances, it is not a routine option for the scientific community. While wideband satellite military communication systems exist, again, they are not available to the scientific or commercial community. Innovative approaches are needed.

Rationale for Partnership: The academic/scientific and the Navy communities have long had a need for better sampling of oceanographic processes. They, in concert with industry also have the engineering capability of developing improved communication systems. Industry has the ability to make the systems both reliable and inexpensive.

Expected Product: Mitigating the limitations upon data acquisition would permit the use of more, and more accurate instruments. All of the research needs associated with the national interests identified in this report require that we constantly improve the ability to get data from the sensors.

Education/Communication

FORMAL EDUCATION - A major change in what we know about how people learn, especially how people learn science, has occurred in two decades. How, what, and why we teach science and mathematics, therefore, must be reconceptualized. The purpose of education is to empower learners to make meaning, in contrast to memorizing a multitude of disconnected facts. What an individual knows about a topic influences the meaning he/she can make of new information. Abstract concepts must be put in the context of experiences with which the learner is familiar. Further, learners cannot be given concepts. They must construct concepts for themselves. Instructional strategies, subsequently, need to focus on learning, rather than on teaching, as transmitting information. Further, the target audience for science education is all Americans, in contrast to science for the elite. Mathematics educators are calling for mathematical literacy for all, and technology educators are speaking of technology education for all instead of limiting it to students bound for the workplace from grade 12. The revolution in science education requires the study of the interactions of science and technology, a transdisciplinary approach.

The oceans have an aesthetic appeal to humans and the study of oceanography is inherently interdisciplinary. The oceanographic community has an opportunity to make the oceans a major context in which to study the interactions of science, technology, and society, from which to learn basic science and mathematical concepts.

Partnerships between oceanographers and educators with current perspectives on learning are necessary. There are reciprocal benefits between the two cultures, oceanography and education. The former focuses on generating new knowledge about the oceans. The latter focuses on tying pieces of information into a whole picture that can be made relevant to other scientists and to non-scientists. Together they can develop new courses.

Oceanography is an ideal platform for education, focusing on the interaction of forces and processes across a palette of disciplines, including biology, chemistry, physics and geology. The oceans are also a wonderful arena for applying concepts in mathematics (everything from the algebra of determining salinity, to the calculus of ocean currents). There are a handful of initiatives throughout the country attempting to build curricula along these lines. The formal educational community (including all components from kindergarten through graduate school) would realize immediate benefit from partnering through the establishment of oceanography-specific coalitions of educators.

Subject: Expansion of Pre-College (K-12) Teacher Programs

Background: There exist too few precollege teachers, specifically elementary teachers who have the content, knowledge and confidence to teach science. This is one of the primary reasons that too many elementary students perform poorly in the sciences. It is well documented that a key to reversing this dangerous lack of scientific understanding demonstrated by students is by teaching teachers. Successful workshops, undergraduate and graduate courses relative to marine sciences should remain as an area of priority and be expanded at the local, state, regional, and national level. When new technologies and/or advances in scientific theory are developed, workshops and courses must be made available for teachers, thereby allowing them to infuse this "new" knowledge and complementary methodologies/activities into existing curricula. New or revised curricular materials may also need to be developed. Teaching/learning experiences to assist with integrating these materials in classrooms would follow.

Opportunity: New and/or extended partnerships need to be developed among the education community and marine scientists in government, academia, and the private sector. These partnerships must include - bur should not be limited to - fiscal support, equipment, personnel and/ or resource materials (hard-copy, audio/video, diskette, laser discs, Internet, or other related types of materials). The ocean science community can collaborate with instructional material developers to produce content- correct and content -current materials, and can rapidly modify existing materials to add new content. "Year-round" academic years for precollege students are increasing in various school districts/parishes within this country. This paradigm shift will provide the opportunity for increasing competitiveness of this country's youth.

Hurdles: The benefit to each partner may not have been delineated due to inadequate marketing strategies or fiscal constraints exhibited by potential sponsors. Recruitment of teachers for enrollment in science classes is often difficult.

Rationale for Partnership: A partnership is necessary since educating and training teachers is a continuous effort. Children represent our future and investing in them through teacher training programs is a "win-win" situation for all the partners involved. The continuous partnership ensures delivery of timely research findings into the classroom.

Expected Product: Teachers who enhance their current knowledge and teaching strategies also have an increased self-confidence which translates back in the classroom in a positive and enthusiastic manner. Marine and aquatic sciences/ oceanography can be taught by teachers and learned by students in a sense of wonder, excitement , and awe.

INFORMAL EDUCATION - The average American probably knows more about space than he or she does about the oceans. Given that so much of quality of life and economic prosperity are dependent on oceanography it is timely to address the need for increased public awareness of this field. The ocean research community is a treasure trove of fascinating findings. There are a very limited number of efforts to provide regular educational opportunities in oceanography for the public (an outstanding recent example is the Smithsonian's Ocean Planet Exhibition, the first traveling exhibition of this kind). Related to this need is the issue of providing information to policy makers at the federal, state, and local levels. A network or coalition is needed to foster this kind of dissemination of information, as well as serving as a focal point for ocean-related issues.

Subject: Marine Information Network

Background: Ocean science data can be too fragmented or hidden in difficult to understand scientific papers with little relevance to "society" or legislators on all levels. The timely, accurate transfer of information (i.e. data, analytical products, synthesis documents) on marine environment issues to public leaders, educators and the general public is crucial if the ocean's role in human activities is to be properly understood. Many problems with stewardship of the marine ecosystem, response to natural and human-induced hazards and the full appreciation of the ocean arise either from the lack of information, or great difficulty in locating relevant data and products, or incompatibility between the few existing delivery systems. Such an informational flow assumes an educational initiative to make the information useful, to supply it in formats compatible with robust analysis packages and provisions for an interested party to obtain more detailed answers dependent on the needs of the particular user.

Opportunity: The current technologies provide various models for making it relatively easy to transmit information. The challenge is to provide a "useful information flow" and a backup set of experts to handle questions. The useful information flow envisioned here would consist of a searchable catalog of data and products together with an efficient delivery system. Such a database must be accessible by multiple users such as media, legislators, public, or anyone looking for information. The opportunity is especially strong now with some on-line networks (e.g. the Virtual Library of Oceanography at http://www.mth.uea.ac.uk/ocean/oceanography.html).

Hurdles: Gathering appropriate data products and maintenance of the information base represent a commitment of resources that must be organized and checked. The true usefulness of the system demands a wide distribution of the products, provision and maintenance of a suite of user software designed to accommodate anticipated data and product types, and an effort to educate users in their use.

Rationale for Partnership: Garnering the breadth of information for the network exceeds the ability of any single entity. Given a distribution system, the network can service both local interests and global issues. The major issue with the partnership will be a steady focal point and a sponsoring agency.

Expected Product: National catalog of data, analysis products, synthesis documents, software, projects, and survey efforts; an overall distributed data/distributed catalog architecture that allows Internet-wide browsing; a data/product delivery system; and a suite of documented software for user display, analysis, re-analysis, or manipulation of the obtained information. This system would be supported by a set of designated experts who can provide additional support to a broad range of users.

Unique Hurdles

The value of partnerships is defined in terms of the guiding principles outlined above. Additionally, the partnerships proposed by the CORE Interagency Partnership Initiative serve as particularly efficient mechanisms for overcoming hurdles, some of which are unique to the oceanographic community. Some of these singular hurdles are:

> *Funding mechanisms* - Ocean science is primarily supported through grants and contracts from government agencies. The lack of a long term foundation of support (e.g. 'hard money' for faculty positions at research universities) dictates that there be mechanisms (including leveraging the infrastructure investments in oceanographic research and development in the military and industrial sectors) to maintain the long term continuity of the community.
>
> *Funding trends* - As shown in Figure 1 the US Federal funding for basic research in ocean sciences effectively has been halved (by virtue of remaining flat) for nearly two decades, while the total Federal support of basic research has nearly doubled. Given the broadening mission of ocean sciences (Table 1) we are increasingly out of balance. The dollars are shrinking while the research requirements grow.
>
> *Multiple Committee Jurisdiction in Congress* - Primary funding for the conduct of basic research in the ocean sciences emanates from the Congress of the United States. Nine Federal agencies seek funding from Congress for ocean science and technology associated with their missions (Table 1). But, to address funding needs of each of these nine agencies, over forty committees and subcommittees of the House and Senate are involved in carrying out their relevant authorization and appropriation responsibilities. As a result, unless there is some clear integrating or cross-cutting process for Capitol Hill when dealing with the broad national policy and programmatic issues surrounding ocean science and technology, any meaningful partnership arrangement limited solely to other stakeholders would lack substance. Better horizontal integration of broad ocean science and technology policy and programs across the many Federal agencies, is necessary if we are to maintain our lead in this critically important area and at minimum cost. This is particularly true during the post cold war reappraisal of national priorities under more constrained budgets. This hurdle to our efforts in ocean science and technology needs addressal by the legislative and executive branches in cooperation.

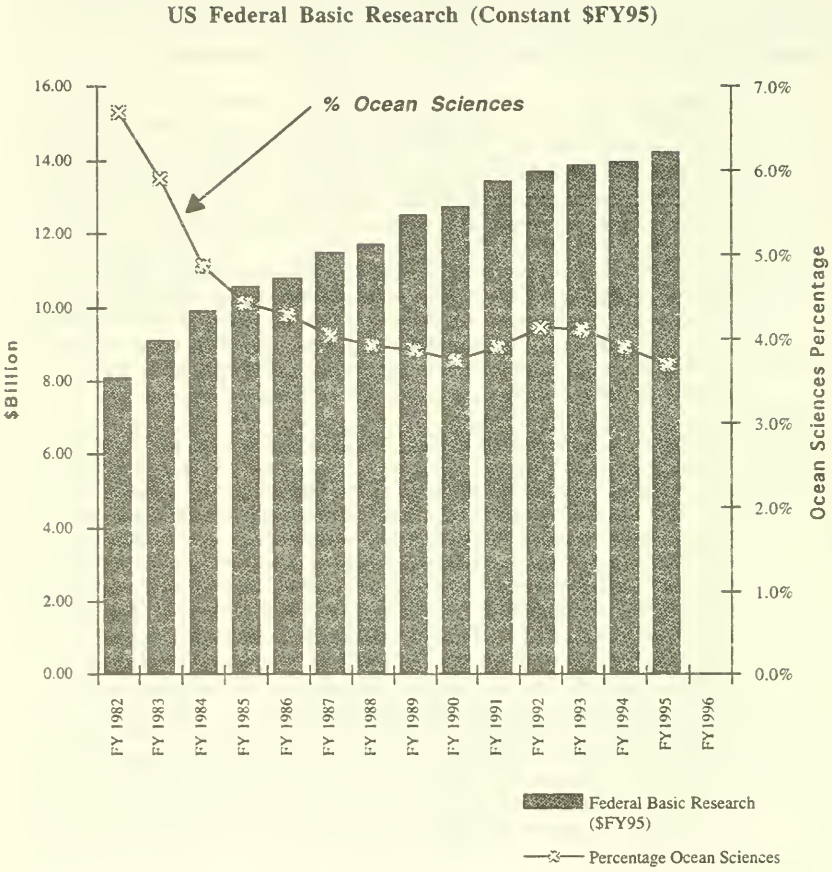
US Federal Basic Research (Constant $FY95)
% Ocean Sciences
$Billion
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Ocean Sciences Percentage
FY 1982
FY 1983
FY 1984
FY 1985
FY 1986
FY 1987
FY 1988
FY 1989
FY 1990
FY 1991
FY 1992
FY 1993
FY 1994
FY1995
FY1996
Federal Basic Research ($FY95)
Percentage Ocean Sciences

Figure 1

AGENCIES INVOLVED IN SUPPORT OF ACADEMIC OCEAN SCIENCES RESEARCH COMMUNITY

(Source is the Ocean Studies Board of the National Research Council.)

AGENCY	MISSION WHICH IS SUPPORTED BY OCEAN SCIENCES RESEARCH	$M TO ACADEMIC OCEAN SCIENCES RESEARCH in FY95	APPROXIMATE NUMBER OF SCIENTISTS SUPPORTED
NSF	Basic research in all disciplines	193.37 (37%)	1500
ONR	National security	103.21 (20%)	800
NOAA	Fisheries, weather, coastal zone management, navigation	79.50 (15%)	600
EPA	Pollutant dynamics, environmental protection, environmental monitoring	41.00 (8%)	300
NASA	Ground truthing for satellite observations of sea surface; large scale oceanographic observations	38.90 (7%)	300
USGS	Coastal erosion and hazard mitigation, mapping, hard mineral resources	36.49 (7%)	250
MMS	Exploration and development of oil and gas resources on outer continental shelf	13.40 (3%)	100
DOE	CO_2 budget, energy sources and transport	11.30 (2%)	85
ARPA	Advanced technology demos, industry coordination	7.00 (1%)	50
USACoE	Ports and harbor management, dredging	negligible	negligible
USCG	Coastal search and rescue, law enforcement	negligible	negligible
Oceanographer of the Navy	Operational navy - systematic characterization and forecasts of environmental conditions	negligible	negligible
CIA	Access/exploitation of declassified data	negligible	negligible
	TOTALS	**$524.17M**	**2100 (see note)**

Note: The total number of scientists does not equal the sum of the numbers in the column, since most scientists receive funding from multiple agencies

Table 1

Security concerns and classified applications - The oceans are the operating environment for our national defense. In fact, it has been argued that the seas of the world are our moats. Any research in oceanography is immediately relevant to the operations of the US Navy and may have implications for national security. As such there will always be an awareness of the contribution of our research and education in oceanography to national security concerns and vice versa.

Management and ownership of resources - The oceanographic researcher depends heavily on a major capital investment that has been made by industry and agencies within the Federal government in terms of research platforms, equipment, laboratories and general infrastructure. The management of these resources, and their ownership is dispersed among public and private entities. Optimal use and upgrade of these facilities requires a delicate coordination of missions, plans and funding.

Further, the *human* resources within the ocean sciences community are heavily concentrated in a limited set of job sectors. Management of the human resources will require a diversification of the job opportunities and new educational initiatives to help prepare students for more alternatives in employment.

Communications - The field of oceanography is represented by approximately 50 different technical journals and no less than 15 professional organizations. While an isolationist approach to one's own research field may have sufficed 50 years ago, the inherently interdisciplinary nature of today's oceanographic issues dictates that the marine researchers and educators have an extraordinarily broad network for communication.

Public Awareness - Some recent dramatic demonstrations of lack of public scientific literacy have emphasized the need to bring oceanographic research results to the forefront of general visibility. The lack of attention paid to marine issues in the media is most likely attributable to a lack of coordinated publicity by the ocean research and education communities; it is not for lack of exciting showpieces from the science and technology being performed in the ocean.

Conclusions

From such prestigious scientific bodies as the National Academy of Sciences and its many associated Boards, from well supported needs statements of the mission oriented federal agencies, and from a variety of highly respected scientific organizations the question of "what to research" in the areas of ocean science and technology is outlined quite well. What is clearly lacking today, however, is any cohesive sustainable and integrated plan on "how to" best achieve our objectives in these important scientific areas, in the most efficient and cost-effective manner. This report identifies opportunities wherein new and enlightened partnerships can be established to provide the bonding agents needed to pull our currently disparate parts together. The report also identifies serious hurdles somewhat unique to the ocean science and technology areas. This report now makes recommendations to establish new institutional processes to eliminate these hurdles and manage ocean science and technology much more efficiently in the future. The experience derived in producing this report provides confidence that these recommendations are quite executable and in the near term.

Recommendations

To help eliminate the identified unique hurdles to the effective and efficient conduct of a comprehensive and integrated national ocean science and technology strategy a new way of doing the nation's business is called for. Specific actions are recommended. These actions will:

- accelerate and improve the applicability of ocean research to the national interests in quality of life, national security, economic development and education/communication, and
- directly address the hurdles identified above.

The recommended actions are targeted to three groups: 1) the performers of research and education in academia, government laboratories, and the private sector; 2) the executive agencies of government responsible for sponsorship and direction of ocean research, and; 3) the legislative branch of government, responsible for authorizing ocean research and development and appropriating funds in that regard.

To this end the following recommendations are made in these areas:

New Partnership Opportunities

Definition of specific research and education opportunities for partnerships: These partnerships should adhere to the principles cited above, and should focus on optimizing the use of data, resources and educational/communication tools. The partnerships should include potential involvement by all sectors of research and education.

Management Blueprint

Integration at the Federal agency and non-Federal agency levels: Develop and implement an integrated Federal agency to non-Federal agency partnership management plan to help provide the desired level of effectiveness and cost efficiencies in the execution of federally-funded ocean science and technology programs.

Congressional Involvement

Involvement of Federal legislators: Specific legislation and Congressional activity must be initiated. Recommendations will deal with short term actions and long term involvement by Congress. These recommendations put in place the pieces needed to carry out the new partnerships and are consistent with the management plan.

NEW PARTNERSHIP OPPORTUNITIES

The new partnership opportunities have been defined in a previous section of this report. These opportunities build upon proven capabilities of the research and educational communities, yet the successful implementation of the partnerships will require a suitable management plan.

THE MANAGEMENT BLUEPRINT

Implementation of partnerships requires, in addition to adherence to the principles outlined previously, a strong, yet flexible, management blueprint. The management issues associated with conduct of research are complicated by the planning, coordination and associated details required of an effective partnership. The management plan must deal in specific terms with the concerns of *resources, personnel, infrastructure, schedules* and *deliverables*. All of these categories must be organized according to an agreed upon set of priorities.

To facilitate the management of the proposed partnership concepts, a management blueprint must be developed immediately to establish the operational structure and guidelines for the concerns listed above.

Resources

The initiatives proposed herein require supplements in funding. The funding source must be centralized to both facilitate its obligation/commitment, and to separate it from the influences of individual mission focus of a specific agency. The investment of resources should be planned to accommodate the plan for implementation of the partnership initiatives over a well-established and agreed upon phase-in period (nominally five years). An estimate of the additional resources required to implement all of the proposed initiatives is $30-50 million per year over that time frame (for a total of $250 million).

Personnel

The issue of staffing is critical to successful implementation of the partnerships. Recalling the partnership principle of 'high-level involvement', there must be a long-standing oversight committee of the principal operational federal agencies, with ex-officio membership from the Federal, academic, industrial and other non-Federal sectors. The critical nature and high visibility required of the partnership activities dictates continued involvement by the highest level representatives of the agencies. This **National Ocean Leadership Council** (NOLC) should be a chartered organization, with formally established membership requirements, leadership structure, dedicated staffing, and meeting schedules. The executive activities associated with project management should be delegated to a group, arguably the same as the Coordinating Group of this partnership initiative. The NOLC would report on an annual basis, highlighting its investment priorities, and products of its efforts, in the context of national needs to the Administration and the US Congress. A conceptual structure is shown in Figure 2.

Infrastructure

The successful implementation of this management plan cannot rely exclusively on periodic convening of the Coordinating Group and NOLC. The working groups shown in Figure 2 would be the agents for developing plans specific to particular issues. Initially the working groups would function as planning forums for specific initiatives, such as those identified in this report. The definition, charge and performance schedule of each working group would be provided by the Coordinating Group. The working groups will require a long-term, full-time management infrastructure. The mechanism best suited to this management is a project office which responds to the direction and sponsorship of the multi-agency Coordinating Group. The example of a successful project office has been demonstrated on numerous occasions; its effectiveness is maintained through a balance of autonomy in how it conducts its business, and formality in its accountability and reporting requirements. Such an infrastructure must also be staffed at a sufficiently high level of responsibility to facilitate strong working relationships with the members of the Coordinating Group and the NOLC and the rest of the community. This project office must also be provided with the authority and resources to implement the recommendations and suggestions of the Coordinating Group.

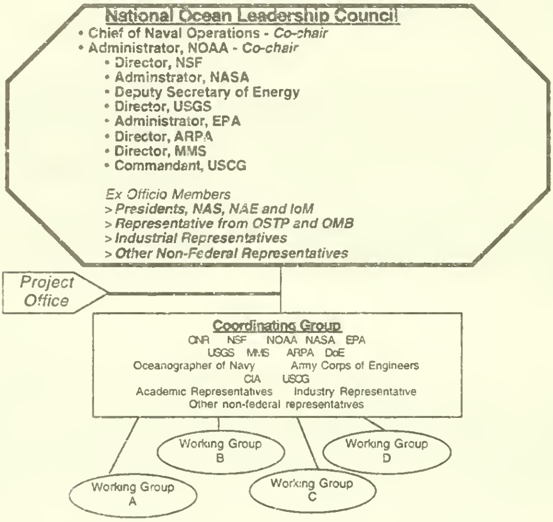
National Ocean Leadership Council
• Chief of Naval Operations - Co-chair
• Administrator, NOAA - Co-chair
• Director, NSF
• Adminstrator, NASA
• Deputy Secretary of Energy
• Director, USGS
• Administrator, EPA
• Director, ARPA
• Director, MMS
• Commandant, USCG
Ex Officio Members
> Presidents, NAS, NAE and IoM
> Representative from OSTP and OMB
> Industrial Representatives
> Other Non-Federal Representatives
Project Office
Coordinating Group
ONR NSF NOAA NASA EPA
USGS MMS ARPA DoE
Oceanographer of Navy Army Corps of Engineers
CIA USCG
Academic Representatives Industry Representative
Other non-federal representatives
Working Group B
Working Group D
Working Group A
Working Group C

Figure 2

Schedules

The NOLC, acting as the oversight and reporting component for the Coordinating Group, and as sponsor to the activities of the project office, will develop reports on an annual basis for the Administration and the US Congress, as specified above. This report will constitute the marine science component of a Federal science and technology investment. In this regard, the annual report from the NOLC can serve as an example component of the implementation of a national science and technology investment strategy (congruent with the current thinking, as best expressed by the recent report of the National Academy of Sciences to the US Congress, "Allocating Federal Funds for Science and Technology", 1995). Scheduling of the annual report by the NOLC should be consistent with the development of Federal budget submissions.

Deliverables

The most significant deliverable from this activity will be the specific initiatives identified in this report. The annual statement from the NOLC should outline the nature of the ocean partnerships in the context of a national investment strategy in marine science. Clearly, such a set of initiatives would be primarily responsive to the objectives of the partners (including the commercial interests of the private sector, the educational and research interests of academia, and the mission-oriented needs of the Federal agencies). Consequently, the definition of products, as specified in the report from the NOLC should be required to address the extent to which such nationally relevant mission statements as the Oceanography Policy of the Chief of Naval Operations (1995), and the NOAA Strategic Plan (1995) are being met.

Specific activities are required to begin the process. The management plan defined in general terms, above, requires the blessing and support of both the Executive Branch and the US Congress. Involvement falls into two categories: facilitation and oversight. Legislative oversight is best provided through the development of a coordinated group of members of Congress with interest in the future of ocean research and education and a recognition of the role such efforts can play in the protection of US interests in national security, economic development, quality of life and education. Such an organization represents the long-term support, supervision and course corrective body needed for maintaining both strength and flexibility in these efforts. The resource exigencies require immediate action in the form of legislation. Arguably the Congressional group alluded to can play a strong role of leadership in the introduction and passage of such enabling legislation.

CONGRESSIONAL INVOLVEMENT

This Interagency Partnership Initiative recommends the following two specific actions in order to initiate the partnership activities broadly defined above.

Establish a Congressional Ocean Task Force

The financial support for research and development of oceanography is largely from public sources, particularly the federal government. Unfortunately, the message of the worth of oceanography is hidden because of the support role it plays to the ocean-related industries and national defense. If the oceanographic community expects to receive the full measure of support for the wide range of investigation topics educational initiatives, and related data bases it requires, convincing arguments must be articulated to decision makers in Congress such that the importance of oceanography is more fully understood and effectively competed in the national budget.

In the 104th Congress, new committees were formed, particularly the Committee on Resources and the Committee on Science as well as a re-casting of the House Armed Service Committee into the National Security Committee. Each of these committees has some functional jurisdiction for oceanography. In addition, the oceanography sector, as previously stated, involves many state, academic, professional and other institutions of interest to members. A forum of information flow is essential for these committees and Members' personal staff.

Federal agencies seek monies from more than forty authorization and appropriation Committees and Subcommittees. In light of the breadth of national missions invoking ocean sciences (Table 1), a focus for Congressional interests is urgently needed. An integrating process does not now exist. The task force we are proposing satisfies that need.

The fundamental objective of a congressional task force would be to provide a forum of information exchange for oceanography and an opportunity for members of Congress to understand its impact on the many business and social sectors that are associated with national defense, economic growth, and quality of life.

A partnership of members of Congress, industry, academia, and others will provide an understanding of budget realities, pressure and prioritization in and outside of the government arena. Without a full understanding budget decisions may be made adversely for oceanography. Conversely, where new opportunities exist for national security or industrial growth, members may seek positive budget adjustments for oceanographic endeavors that will enhance the discipline.

The product from such a task force will be a cohesion of practical leaders supporting oceanography in those budget lines that require state-of-the-art oceanographic products. The fact that the partnership (cross-agency and industrial) can provide a "good news", cost savings initiative on the part of the oceanographic community will demonstrate that we are not "business as usual" thinkers.

Pass Ocean Partnership Legislation

There are two major milestones in the approach to strengthening the impact on society of the oceanographic community: visibility and backing. The oceanographic community is not limited in its ideas for implementation of new partnerships (in fact, the Interagency Partnership Initiative served to generate over 100 specific ideas for new partnerships). The visibility required to launch this partnership initiative can be accommodated through the development of the task force described above. Backing must come in the form of substantive support, specifically as enabling legislation which also defines the structure and operation of the National Ocean Leadership Council.

Legislation supporting the definition, development and implementation of partnerships in oceanography will provide the impetus needed at a critical time. The United States is looked upon by the world as a leader in both technology and policy for the marine environment. Nearly thirty years ago this nation took a bold step forward in redefining our national investment in ocean sciences, through the implementation of the recommendations of the Stratton Commission. The opportunity for a 'reinvention' of federal support for oceanography is upon us. Through legislation written in defense of developing ocean partnerships this community of researchers and educators will be charged with identifying specific mechanisms to position our nation in a leadership role. Congress will be laying the groundwork to carry oceanography and our society into the next millennium.

References

Department of the Navy. 1995. Office of the Chief of Naval Operations. Naval Oceanography Policy. Washington, DC.

National Academy of Sciences. 1995. Allocating Federal Funds for Science and Technology. ISBN 0-309-05347-1. National Academy Press. Washington, DC.

National Oceanic and Atmospheric Administration. 1995. NOAA Strategic Plan: A Vision for 2005. Washington, DC.

National Research Council Committee on Biological Diversity in Marine Systems, 1995. Understanding Marine Biodiversity. ISBN 0-309-05225-4. National Academy Press. Washington, DC.

National Research Council Ocean Studies Board. 1992. Oceanography in the Next Decade: Building New Partnerships. ISBN 0-309-04794-3. National Academy Press. Washington, DC.

National Science Foundation. 1991. Characteristics of Doctoral Scientists and Engineers in the United States: 1989. NSF 91-317. Washington, DC.

State-Federal Technology Partnership Task Force Final Report. 1995. Gov. Richard Celeste. and Gov. Dick Thornburgh, Co-chairs, Carnegie Commission on Science, Technology and Government.

APPENDIX I

PARTNERSHIP COORDINATING GROUP MEMBERSHIP

MEMBER	AFFILIATION
ADM James Watkins (Chair)	Consortium for Oceanographic Research & Education
Dr. Donald Boesch	University of Maryland
Dr. Robert Corell	National Science Foundation
RADM George Davis	Oceanographer of the Navy
Dr. Robert Harriss	National Aeronautics and Space Agency
Dr. Martha Krebs	Department of Energy
Dr. Bonnie McGregor	United States Geological Survey
RADM Bradford Mooney	Independent Contractor
Dr. John Orcutt	Scripps Institution of Oceanography
Dr. Ned Ostenso	National Oceanic and Atmospheric Administration
Dr. William Raub	Environmental Protection Agency
Dr. Fred Saalfeld	Office of Naval Research
Mr. Charles Stuart	Advanced Research Projects Agency
Dr. Kathryn Sullivan	National Oceanic and Atmospheric Administration

APPENDIX II

PARTNERSHIP STEERING COMMITTEE MEMBERSHIP

MEMBER	AFFILIATION
Dr. Arthur Nowell (Chair)	University of Washington
Dr. Miriam Baltuck	National Aeronautics and Space Administration
Dr. Cheryl Ann Butman	Woods Hole Oceanographic Institution
Dr. James DeCorpo	Office of Naval Research
VADM Frank Donovan	PRC, Inc.
Dr. John Downing	Battelle Pacific Northwest Laboratory
Dr. Paul Falkowski	Brookhaven National Laboratory
Mr. John Flipse	Marine Technology Society
CAPT Kent Foster	Office of the Oceanographer of the Navy
Dr. J. Frederick Grassle	Rutgers University
Dr. Donald Heinrichs	National Science Foundation
RADM Wes Jordan	National Security Industries Association
Dr. Roy Jenne	National Center for Atmospheric Research
Mr. Amor Lane	Marine Technology Society
Dr. Thomas Malone	University of Maryland
Dr. Janet Morton	US Geological Survey
Dr. John Orcutt	Scripps Institution of Oceanography
Dr. Curtis Olsen	Department of Energy
Dr. Leonard Pietrafesa	North Carolina State University
RADM Richard Pittenger	Woods Hole Oceanographic Institution
Dr. William Raub	Environmental Protection Agency
Dr. Mike Reeve	National Science Foundation
Dr. Robert Spindel	University of Washington
Dr. Ken Turgeon	Minerals Management Service
Mr. Keith Vickery	National Ocean Industries Association
ADM James Watkins	Consortium for Ocean Research & Education
Mr. Robert Winokur	National Oceanic and Atmospheric Administration
Additional attendees:	
Mr. Robert Feden	National Oceanic and Atmospheric Administration
Ms. Mary Hope Katsouros	Ocean Studies Board
Mr. Ed McWethy	Office of Naval Intelligence
Mr. Robert Moran	National Ocean Industries Association
CAPT Evan Robinson	Office of Naval Intelligence
Mr. Terry Schaff	Consortium for Ocean Research & Education
Dr. Richard Spinrad	Office of Naval Research
Dr. Linda Zall	Central Intelligence Agency

APPENDIX III

PARTNERSHIP WORKING GROUP MEMBERS

Chair, Quality of Life: Dr. Mel Briscoe **22-24 May 1995, Washington, DC**

MEMBER	AFFILIATION
Dr. Vera Alexander	University of Alaska
Dr. Donna Blake	National Aeronautics and Space Administration
Dr. Melbourne Briscoe	National Oceanic and Atmospheric Administration
Dr. Murray Brown	National Oceanic and Atmospheric Administration
Ms. Lynne Claflin	Consortium for Oceanographic Research & Education
Dr. Paul Dauphin	National Science Foundation
Dr. Sylvia Earle	Deep Ocean Engineering, Inc.
Dr. Paul Epstein	Cambridge Hospital, Department of Medicine Harvard University
Dr. J. Frederick Grassle	Rutgers University
Dr. Roy Jenne	National Center for Atmospheric Research
Dr. Alan Mearns	Marine Technology Society
Dr. Arthur Nowell	University of Washington
Dr. Curtis Olsen	Department of Energy
Dr. Donald Olson	University of Miami
Dr. David Paskausky	US Coast Guard R&D Center
Dr. William Raub	Environmental Protection Agency
Mr. Terrence Schaff	Consortium for Oceanographic Research & Education
Dr. Eric Shulenberger	Office of Naval Research
Dr. Richard Spinrad	Consortium for Oceanographic Research & Education
Ms. Macol Stewart	NOAA Office of Global Programs
Dr. C. Linwood Vincent	US Army Corps of Engineers
ADM James Watkins	Consortium for Oceanographic Research & Education
Dr. S. Jeffress Williams	United States Geological Survey
Dr. Charles Yentsch	Bigelow Laboratory for Ocean Sciences

Chair, Economic Development: Dr. Eric Hartwig **14-16 June 1995, Washington, DC**

MEMBER	AFFILIATION
Mr. Timothy Askew	Harbor Branch Oceanographic Institute, Inc.
Mr. Philip Beachem	NJ Alliance for Action
Dr. Melbourne Briscoe	National Oceanic and Atmospheric Administration
Dr. James Brooks	Texas A&M
Mr. Robert Burkart	Industrial Research Institute, Inc.
Ms. Kathleen Cevoli	University of Rhode Island
Ms. Lynne Claflin	Consortium for Oceanographic Research & Education
Dr. Mike DeLuca	Rutgers University
VADM Francis Donovan	PRC Inc.
Dr. John Downing	Battelle Marine Sciences, Pacific Northwest Laboratory
Dr. David Epp	National Science Foundation
Dr. Eric Hartwig	Naval Research Laboratory
Mr. Michael Hastings	Maine Aquaculture Innovation Center
Mr. James Knox	Consortium for Oceanographic Research & Education
Mr. Amor Lane	Marine Technology Society
Dr. James Luyten	Woods Hole Oceanographic Institution
Dr. John Marra	Lamont Doherty Earth Observatory
Dr. Arthur Nowell	University of Washington
Dr. Andrew Palowitch	Oceaneering Technology, Inc.
Dr. Steven Ramp	Office of Naval Research
Dr. Richard Rein	Naval Research Laboratory
Mr. Terrence Schaff	Consortium for Oceanographic Research & Education
Dr. Richard Spinrad	Consortium for Oceanographic Research & Education
Dr. Ken Turgeon	Department of Interior, Minerals Management Service
Dr. Joseph Uravitch	National Oceanic and Atmospheric Administration
Mr. Keith Vickery	Sonardyne, Inc.
ADM James Watkins	Consortium for Oceanographic Research & Education
Dr. James Yoder	University of Rhode Island
Mr. Dana Yoeger	Woods Hole Oceanographic Institution

Chair, Education/Communication: Dr. Len Pietrafesa 10-12 July, 1995, Raleigh, NC

MEMBER	AFFILIATION
Mr. Kerry Bolognese	National Association of State Universities & Land Grant Colleges
Ms. Chris Carmody	Consortium for Oceanographic Research & Education
Ms. Nora Deans	National Marine Educators Association
Dr. Mike DeLuca	Rutgers University
Dr. Quenton Dokken	Texas A&M University - Corpus Christi
Dr. Sharon Roth Franks	Scripps Institution of Oceanography
Ms. Judith Gradwohl	Smithsonian Institution
Mr. Robert Heinmiller	Omnet, Inc.
Dr. Frank Ireton	American Geophysical Union
Mr. James Knox	Consortium for Oceanographic Research & Education
Dr. Thomas Malone	North Carolina State University
Dr. Livingston Marshall	University of Maryland, Eastern Shore
Mr. Stewart Nelson	Consultant
Dr. Leonard Pietrafesa	North Carolina State University
Mr. Terrence Schaff	Consortium for Oceanographic Research & Education
Dr. Barbara Spector	University of South Florida
Dr. Richard Spinrad	Consortium for Oceanographic Research & Education
Dr. Sharon Walker	Gulf Coast Research Laboratory Mississippi-Alabama Sea Grant Consortium
ADM James Watkins	Consortium for Oceanographic Research & Education
Dr. Alan Weinstein	Office of Naval Research
Dr. Peter Wilkniss	National Science Foundation
Ms. Maureen Wilmot	National Oceanic and Atmospheric Administration
Ms. Joy Wolf	Sea World of California
Dr. Xiao-Hai Yan	University of Delaware
Dr. Clarice Yentsch	Bigelow Laboratory for Ocean Sciences
Dr. James Yoder	University of Rhode Island

Chair, National Security: RADM Dick Pittenger 31 July -2 August 1995, Seattle, WA

MEMBER	AFFILIATION
Mr. William Andahazy	US House of Representatives
Mr. Richard Arthur	Sippican, Inc.
Dr. Arthur Baggeroer	Massachusetts Institute of Technology
Dr. Alan Beam	Pennsylvania State University
Dr. Melbourne Briscoe	National Oceanic and Atmospheric Administration
Dr. Otis Brown	University of Miami
Ms. Lynne Claflin	Consortium for Oceanographic Research & Education
Mr. George Clausen	CMA, Inc.
LT John DiMento	Naval Meteorological & Oceanography Command
Mr. Robert Feden	National Oceanic and Atmospheric Administration
RADM Paul Gaffney	Naval Meteorological & Oceanography Command
Dr. Kenneth Hawker	MITRE Corporation
Dr. Donald Heinrichs	National Science Foundation
Mr. Lawrence Jendro	US Coast Guard Headquarters
RADM Wes Jordan	BBN Systems and Technologies
LT Robert Donald Kelso	Navy Office of Legislative Affairs
Mr. John Mariano	AT&T Submarine Systems, Inc.
Mr. Norman Mosher	965 Inc.
Dr. Arthur Nowell	University of Washington
Dr. John Orcutt	Scripps Institute of Oceanography
Dr. Harold Palmer	MRJ, Inc.
CAPT Richard Pentimonti	Oceanographer of the Navy
RADM Richard Pittenger	Woods Hole Oceanographic Institution
Dr. Steven Ramberg	Office of Naval Research, OAS Sensing & Systems Div.
Dr. Donald Resio	US Army Corps of Engineers
Mr. Terrence Schaff	Consortium for Oceanographic Research & Education
Dr. Paul Scully-Power	Naval Undersea Warfare Center
RADM J. Richard Seesholtz	The Johns Hopkins University Applied Physics Laboratory
Dr. Robert Spindel	University of Washington Applied Physics Laboratory
Dr. Richard Spinrad	Consortium for Oceanographic Research & Education
ADM James Watkins	Consortium for Oceanographic Research & Education
Dr. Creighton Wirick	Department of Energy, Brookhaven National Laboratory

Appendix IV

PAST PARTNERSHIPS

Appendix IV.A.

Title: Eddy Joint Industry Project (EJIP)

Issue: How can we identify and monitor Loop Current (LC) eddies in the Gulf of Mexico that might impact offshore oil and gas operations?

Relevance: Loop Current eddies range in sizes from 100 to 400 km in diameter, and have maximum current speeds of 3-4 knots. Because they have the potential to disrupt offshore oils and gas operations (or endanger life and property), their presence and anticipated movements are of great importance. Eddy events along the southern Louisiana coast usually last 1-4 weeks at any given site, and may cause a $100k/day losses.

Background And Approach: Since the early 70's loop current eddies have been watched closely by offshore industry and the Minerals Management Service (MMS of the Department of Interior) as potential threats to operations. With the movement of offshore oil and gas activities onto the upper slope in the mid-80's, effective means of continual monitoring was essential. To meet the need, several oil and gas companies formed a Joint Industry Project (JIP) to perform hydrographic surveys in suspected eddies and to deploy drifting sensor packages in confirmed eddies. The MMS was initially performing independent studies of eddy dynamic properties to support modeling, but opted to join the project and donated instrumentation and expertise.

Partners: Minerals Management Service, Exxon, Shell, Marathon, Texaco, Chevron

Motivating Factor: The partnership clearly saved money for all partners, but a further bonus was the sharing of ancillary data.

Products: Charts of hydrographic survey results, drifting buoy trajectories, data transferred to the National Oceanographic Data Center (NODC).

Impact Or Benefit: Over the period of 1985-1993, approximately 15 eddies were monitored, resulting in greatly improved predictability of their general behavior and increased warning time. The individual leveraging factor would have been about 6:1 as each company shared equally in the costs.

Lessons Learned: Although traditional industrial data management practice has been quite conservative, the offshore oil and gas sector has been flexible and accommodating in the cooperative work with a federal agency. A number of practical matters were identified to make these dealings smoother, but no fundamental impediments were identified.

Appendix IV.B.

Title: MEDEA: Scientific Utility of Naval Oceanographic Data

Issue: What is the quality of Navy held classified/unclassified data sets and modeled data, and what is its civil utility?

Relevance: By increasing access to Navy's vast global ocean data, it is possible to gain new knowledge about ocean processes with utility for the Navy and civilian concerns. The review resulting from this partnership could also serve to verify or modify the Navy's ocean data collection and management skill.

Background and Approach: Building on the bi-partisan Environmental Task Force (ETF) experience of 1992, the Commander Naval Meteorology and Oceanography Command asked the ETF successor group, MEDEA, to review Navy data and model holdings for quality and civilian utility. A report of their findings was published in July 1995. The approach used was modeled on ETF's review of reconnaissance satellite imagery. Twelve scientists from academia and industry were cleared to see Navy classified data. They reviewed the data at Navy's three oceanographic production/archival centers together with Naval officers and civilians. The final report, the product of the MEDEA panel, made judgments on data and data management quality, recommendations on data declassification and recommendations for subsequent Navy-civilian partnerships.

Partners: Navy, academia, industry, Central Intelligence Agency

Motivating Factors: To potentially increase oceanographic knowledge for Navy and civilian purposes by making vast new data sources available to the nation's scientists, assuming some part of the classified data could be declassified. The motivating philosophy of the study was: "security through achievement, not concealment".

Products: An in-depth review which validated the quality of Navy data; a report which lays out a list of data sets with civilian utility; re-established long dormant ties between Navy's operational oceanographers and the nation's top civilian research oceanographers.

Impact: The real impact on scientific knowledge is yet to be seen and will in part be based on Navy declassification actions over the next year or two. However, closer ties and great understanding between the Navy and civilian oceanographers has already accrued.

Lessons Learned: Such experiences cannot be so successfully completed without strong commitment of both sides. Top quality people, compensated for their time, guarantees a good product.

Appendix IV.C.

Title: World of Water Program

Issue: How can middle school students engage in the rigorous and effective study of mathematics, science, and computers while having fun?

Relevance: Much of the American adult population has negative attitudes towards learning science and mathematics which has lead to scientific and technological illiteracy and behaviors that threaten our environment.

Background and Approach: Middle school students participated in a residential program at the University of South Florida for 2 weeks. Community resources pertaining to water were used to illustrate the interpretation of mathematics, science, technology, and society to preserve the environment. Basic mathematics and science concepts were studied on a need-to-know basis as they arose during inquiries in different environments (e.g. the physics of sailing, the chemistry of the oceanarium at EPCOT, the biological and chemical processes in sewage treatment at a tertiary plant).
Exploring mud flats and snorkeling enabled students to collect data about organisms in their natural habitats. Things as diverse as mariculture, hurricanes, regulations regarding turtles and fisheries, and beaching of whales, the scarring of manatees, and water-related entertainment contributed to understanding the impact of oceanography on Florida's economy.

Partners: College of Education at the University of South Florida, several other colleges at the University of South Florida, Florida State Legislature, Florida Department of Education, Florida Department of Natural Resources, Florida Institute of Oceanography; Red Cross, Tampa Bay Port Authority, Florida Phosphate Council, IBM, GTE, Hooker Point Waste Water Treatment Plant, local TV station, local newspaper, all the K-12 school districts in Florida, private sailboat owners, county parks/departments.

Motivating Factor: Partners perceive themselves to be stakeholders in improving education locally and it was good publicity for everyone involved.

Products: Activities that teachers could perform with their own classes during the year, contacts with the oceanographic community, a model for transdisciplinary education, a model for collaborative management in schools.

Impact or Benefit: For 9 years the program served to motivate students to perform well in regular schools so they would be successful candidates for the World of Water Program. Teachers had opportunities to turn theory into practice. Research on the program generated a model for middle school education. Many participants in the program have become science majors and have expressed new-found concern for the marine environment.

Lessons Learned: The key to success in learning is developing a teaching/learning environment which learners perceive to be risk free, therefore encouraging them to take the intellectual risks necessary for creative concept building. This model has been extrapolated to audiences from elementary schools to graduate schools. Discovering ways to work with a multitude of diverse organizations toward a common goal was another profitable lesson.

Appendix IV.D.

Title: JASON Project

Issue: Bringing real time science to students through telepresence

Relevance: Via telepresence, students watch and participate in scientific research as it is conducted in the field and laboratories.

Background and Approach:
Dr. Robert Ballard of Woods Hole Oceanographic Institution (WHOI), while exploring the Titanic wreck site used a remotely operated vehicle (ROV), Jason Jr., tethered to the deep submergence vehicle, Alvin. Jason Jr., or "JJ" as the ROV was referred to by crew members, included video cameras and was controlled from the Alvin. Ballard realized that it would be possible to send the video images back to the surface and broadcast to laboratories or other sites. Ballard teamed with Electronic Data Systems (EDS), Turner Broadcasting System (TBS) and museums in the United States and Canada to form the JASON Foundation for Education. For a two week time period EDS supplies the telecommunications technology from the dive sites and combines it with prepared material to produce four 50 minute programs a day for two weeks. The show is sent via satellites to the museum sites for screening on large projection systems. Students attend the sessions and, through interactive links, are able to question scientists on site and control the ROV. In addition to the scientists, their support staff, and the television crews, students and teachers are selected to accompany the team. The students and teachers take part in the broadcast and work with the scientists during the broadcasts and visit other sites of interest. Since the first program in 1989 to the Mediterranean Sea, the JASON project has visited the Great Lakes, Galapagos Islands, Belize, Sea of Cortez and Hawaii. During the initial years of the program the National Science Teachers Association (NSTA), funded by a grant from the National Science Foundation, developed a curriculum for teachers to use to prepare students for the excursion to the museum. The National Council for the Social Studies (NCSS), EDS, TBS, museum sites and the JASON Foundation for Education assisted in the development of the curriculum. The curriculum integrates technology, science, mathematics, and social studies into a series of activities designed to provide background information to the student so the museum visit becomes more than an outing to watch a television broadcast. A key component of the curriculum project was teacher enhancement sessions at the museum sites to introduce the curriculum.

Partners: Private foundations, professional societies (NSTA, NCSS), government (NSF and ONR), industry (EDS and TBS), museums and science centers, school districts, academia.

Motivating Factor: The major motivation was to give students a chance to watch science in action thus countering some of the stereotypical characterizations of scientists.

Products: JASON curriculum materials (one for each year), two weeks of live broadcasts and thousands of motivated students, as well as an established site on the World Wide Web (http://seawifs.gsfc.nasa.gov/Jason.html).

Impact or Benefits: Increased student awareness of scientific processes, the nature of science as an integrated endeavor, and the possible career opportunities in science and technology.

Lessons Learned: The curriculum is vital in that it helps students understand the nature of the live program they are watching. The teacher workshops are necessary to introduce the scope of the materials to the teachers.

Appendix IV.E.

Title: Institute for Naval Oceanography (INO)

Issue: How can the Navy best "jump start" its numerical ocean modeling capability?

Relevance: Being able to analyze and predict key ocean structure features on a basic scale, much as had been done with weather, would help Navy decide where best to place their tactical assets and optimize their weapons.

Background and Approach: At the time, mid-1980s, it was thought that ocean modeling, remote sensing and computational capabilities had all matured to the level that a real "sea change" in ocean prediction capability would occur if effort and resources were focused on that single mission; a mini "Manhattan Project" for the oceans. The Chief of Naval Operations (CNO) and Secretary of the Navy, in 1984, created a quasi-government organization with the Naval Oceanographic Research and Development Activity (NORDA) in Mississippi to work on this single initiative. INO was a contract organization under University Consortium for Atmospheric Research (UCAR), but imbedded within NORDA. INO was funded with basic research, exploratory development, and advanced development moneys, basic research being the largest contributor by far. The work was restricted to the unclassified. The INO was disbanded in 1992 at the recommendation of the Commanding Officer/Director of Research of the Naval Research Lab (the evolutionary home for INO) with concurrence of the President UCAR. The dissolution was approved by the Chief of Naval Research (CNR).

Partners: Navy, UCAR, academic investigators, and an academic advisory board.

Motivating Factor: Opportunity to "jump start" a global ocean modeling capability for the Navy with obvious spillover to meet civil oceanographic interests.

Products: Several data assimilation, handling, analysis, and predictive techniques and conduct of several model "bake offs" using standard data sets.

Impact: Some benefits in technique development, albeit not in the jump-start category. Direct focus on the burgeoning national ocean modeling capability at several universities.

Lessons Learned: To be successful, an initiative such as INO requires highly visible, consistent support at the highest levels. Long-term commitment, in accordance with the mission of the organization, is also required. The institution must also be defined so as to avoid duplication of similar efforts, while allowing a mission which complements those other organizations.

Appendix IV.F.

Title: The National Ice Center (NIC): A twenty year partnership.

Issue: How can real time global ice information and operational ice predictions be developed and delivered to government and private users in a time of decreasing resources?

Relevance: In the submarine/ballistic missile age the Arctic Ocean is an important area of potential military conflict. Arctic research expeditions conducting military related research need ice information. World wide ice coverage is also relevant to questions of global climate change.

Background and Approach: The National Ice Center provides real-time worldwide ice information and predictions to support Polar Naval operations, Coast Guard icebreaker operations in the Arctic, Antarctic, Great Lakes and NE US Coast. It was called the Joint Ice Center (JIC) until April 1995 when ongoing US Coast Guard (USCG) participation was recognized with a Memorandum of Agreement (MoA). By formal definition, the National Oceanic and Atmospheric Administration (NOAA) provides satellite data and personnel, Navy provides analysis of data, personnel and organizational leadership, and USCG provides aircraft, sensors, and personnel.

Partners: Navy, NOAA and US Coast Guard

Motivating Factors: Decreasing assets with continuing need for ice products by all partners. Need for diverse, expensive facilities to support mission: satellite data/processing, aircraft, sensors, expert personnel.

Impact or Benefit: The NIC has become the US center of excellence in the analysis of satellite/ airborne ice imagery. It is currently the national center and Washington DC communications node for Synthetic Aperture Radar (SAR) data downlinked to the Alaska SAR facility and the national center for the creation of operational ice products from satellite SAR images.

Lessons Learned: (1) Formally established interagency organizations in which products are valuable to all participants can share resources/personnel and leadership to serve all partners; (2) Partnerships can develop significant national capabilities beyond the capacity of any single agency; (3) Well defined organizational structure and responsibilities and flexibility in the use of uncommitted but often available resources have supported NIC success.

Appendix IV.G.

Title: The Sea Grant College Program

Issue: How to support and encourage high quality university-based applied marine research, education and extension, consistent with NOAA marine stewardship missions.

Relevance: Through university-based research programs, Sea Grant directly influences marine resource development and management by providing research, advice and outreach services. Research focus includes marine resource development (i.e., fisheries, marine biotechnology), ecosystem protection, and estuarine resource management addressing NOAA mission issues on a local level. Sea Grant education and extension functions provide the means to disseminate information to the public and, in an interactive mode, to targeted user groups.

Background and Approach: Individual Sea Grant institutions, working with local universities, issue a Request for Proposals to conduct relevant research as defined through an interactive process with NOAA. The Sea Grant institution then prepares a two-year omnibus proposal consisting of a number of sub-proposals, which are subjected to a merit review by NOAA. A final program is then negotiated within budgets provided by Congress. There is a 33% cost share required by law which consists of state and industry dollars.

Partners: NOAA, academia, state agencies and legislatures, private industry, and sometimes, other Federal agencies.

Motivating Factor: The need to support and encourage applied marine research on a local or regional level by utilizing the already existing expertise resident in oceanographic research institutions. Also, the need for a local mechanism to disseminate information.

Products: The Sea Grant program provides research results, workshop proceedings, informative publications, graduate student stipends, Congressional fellowships, advice to coastal communities, and training.

Impact Or Benefit: Sea Grant allows academics to conduct research not normally supported by agencies with extramural funds (e.g. fishery research). Allows academics to better serve the marine community within the states. Makes research findings and results relevant by providing an information transfer mechanism.

Appendix IV.H.

Title: Ocean Technology Center (A NSF Sponsored Industry-University Cooperative Research Center)

Issue: The Ocean Technology Center structure offers its members opportunities to direct research in marine-relevant areas of interest that may be applied (but not limited) to such end uses as the development of new products and services. It also provides a forum for exchanging ideas among the members and access to university faculty and facilities that can address specific technical problems.

Relevance and Background: Although the Center is relatively new (October 1993), it builds on a tradition of marine system development at the University of Rhode Island. Expertise in areas such as acoustical ocean mapping and environmental monitoring systems present opportunities for transfer from a cold war military mission to changing federal and private sector markets. An Industrial Advisory Board made up of Center members directs research topics to ensure that they are relevant to this marketplace.

Partners: National Science foundation, Naval Oceanographic Office, US Geological Survey, Pacific Marine Geology Branch, Naval Underwater Warfare Center, Raytheon, Datasonics, Inc., SEA CORP, SeaBeam, Applied Science Associates.

Motivating Factor: The Ocean Technology Center was developed to address common areas of interest between the industrial/federal laboratory/university communities in marine-related technologies. Members have access to all results of Center-sponsored research and may obtain exclusive rights to intellectual property.

Products: During its first year of operation, the Center launched five projects. One project will develop a communications and display network to support coastal environmental monitoring, while another is investigating the properties of "acoustic bullets." An underwater winch system developed during the first seven months of the Centers' existence promises to become its first success story.

Impact or Benefit: The objective of the Ocean Technology Center is to offer its expertise in marine technology to appropriate public and private sector interests that will create opportunities for the development of new products, services and technologies.

Lessons Learned: Greater industrial involvement is needed as the Center goes forward. Research direction initially was proposed by academics and disposed by the Industrial Advisory Board. Flexibility in the program will allow changes to the structure. In fact, efforts are underway to modify the process of research direction. Additional financial and technical resources can be included to define new markets and assist in getting from product concept to market particularly for smaller industrial members.

Opportunity: The Ocean Technology Center can be used as a mechanism to launch marine technology related initiatives that can benefit the overall economic development of Rhode Island and the region.

Appendix IV.I.

Title: Operation Pathfinder: Oceanography and Coastal Processes for Elementary and Middle School Teachers of Predominantly Minority Students

Issue: Elementary and Middle School teachers desire and need enhanced knowledge relative to oceanography and coastal processes. This study is also a form of recruitment for minority students in the sciences.

Relevance: Since more and more people are moving to this country's coasts, people in general need to be more aware of the fragility and interconnectedness of this watery planet. Increased numbers of minorities should be vital components of this multidisciplinary arena.

Background and Approach: A two-week, three semester hour graduate course is being taught in six different regions of the country. The content of these courses involves marine and estuarine pollution, deep sea technologies, marine and aquatic habitats, plate tectonics, physical parameters, and marine and aquatic resources. Each region may have a maximum of twenty teachers of predominantly minority students. Teachers are provided resource materials and must each develop a homework assignment on each of the six topics. Six cooperative groups of three or four teachers design and implement a staff development program which is presented in class and subsequently presented in his/her school district. Guest scientists and field trips reinforce these content areas.

Partners: US Navy (Office of Naval Research, Oceanographer of the Navy, Naval Meteorology and Oceanography Command, Naval Research Laboratory), Department of Interior's Office of Territorial Affairs, Sea Grant Program, NOAA's Sea Grant Program, NOAA's National Environmental Satellite, Data and Information Service (NESDIS), National Marine Educators Association (NMEA), and academia (the program is hosted by an institution of higher learning in each region).

Motivating Factor: Teaching teachers and introducing increased numbers of minorities to the sciences.

Products: Teachers with augmented content knowledge teaching skills; students with enhanced understanding of the species interconnectedness of the marine environment; resource materials which can be integrated within existing curricula; and minority recruitment strategies.

Impacts or Benefit: The "multiplier effect" inherent in teaching teachers is usually cost and time effective.

Lessons Learned: Success can be attributed to need and partners enthusiasm and vision in sharing costs and meeting the educational challenges of the 21st century.

Appendix IV.J.

Title: Academic Fleet and Deep Submergence Assets

Issue: How can the nation provide and maintain premier capability for facilities for oceanographic research, training, and education?

Relevance: A modern and efficient research ship fleet, including deep submergence assets, is essential to meet research requirements for all major oceanographic programs.

Background and Approach: The academic research fleet in the 1950s and 1960s consisted primarily of surplus ships from the war effort. In the early 1970s the University-National Oceanographic Laboratory System (UNOLS) was established with membership by all major ship operating institutions and federal sponsor agencies. Basic principles include open access to all UNOLS vessels by all federal, state, and local research programs, joint planning for new and replacement ships with open competition, and common operating, safety, and budgetary standards. Deep submergence assets, i.e., ALVIN, were added in the mid-1970s and expanded to include programs for Navy operational assets in early 1990s, i.e., NR-1, Sea Cliff, Turtle, and access to fleet submarines for Arctic research.

Construction of new research ships from 1970 hence was a three-way partnership between Navy, NSF, and academic institutions and was based on plans cooperatively developed through this partnership. In general, Navy built the larger replacement research ships with expeditionary and global capabilities, National Science Foundation built and acquired intermediate ships for regional and coastal srudies, and institutions provided smaller ships for local research. Operations support is provided by nine federal agencies and as required state and institutional sources. The 28 ships of the UNOLS fleet coupled to deep submergence science assets and operating agreements provide the world's premier capability for oceangoing research.

Partners: Research ships were constructed or acquired by Navy, National Science Foundation, and some institutions with Navy providing most major facilities. Deep submergence capabilities provided by Navy. Operations support is primarily from National Science Foundation with significance participation by the Office of Naval Research and the National Oceanic and Atmospheric Administration and lesser use by Department of Energy, United States Geological Survey, Environmental Protection Agency, Minerals Management Service, Advanced Research Projects Agency, Navy laboratories, and institutional sponsors.

Motivating Factors: Capital costs for seagoing platforms-ships and submersibles are very large. Capabilities required to meet research needs of different agencies are similar. Common benefit to all agencies from shared-use facilities.

Products: Oceanographic data and research studies.

Impact or Benefit: US has the premier academic research fleet in the world with cost savings to all federal agencies. There is no duplication of facilities, and enhancements and improvements by any sponsor available to all parties. The combination of Navy-led capital improvements and provision of access to Navy operational deep submergence assets with NSF-led operations support enabled the US community to obtain and operate the research facilities required for international leadership in ocean sciences.

Lessons Learned: UNOLS is very successful with a minimum of conflict. The key is a clear statement of common objectives and a common interest of federal sponsors and users and academic institutions. Academic control of management and operations of research ships to meet institutional and national needs with federal oversight and leadership of capital asset acquisition and assignment has worked very effectively.

Appendix IV.K.

Title: California Cooperative Oceanic Fisheries Investigations (CalCOFI)

Issue: How can we predict the success of pelagic fishery stocks?

Relevance: Predictions can be used to manage the fisheries (sardine, mackerel, anchovy).

Background And Approach: Warnings of the imminent collapse of the sardine fishery in the 1940's prompted California biologists and oceanographers to pool resources and start monitoring fish, plankton and oceanographic processes at a scale encompassing the California current ecosystem. Cooperation between the National Marine Fisheries Service (NMFS), California Fish and Game Department, Scripps Institution of Oceanography, and Hopkins Marine Station lead to joint monthly, quarterly and annual cruises along the present transect from Oregon to Baja California. Dynamics of sardine population and recruitment were defined in the context of interannual ocean variability. Predictions were made and provided to managers for action. The program continues today.

Partners: Scripps Institution of Oceanography; NMFS La Jolla (NOAA vessels), California Department of Fish and Game (state vessels); Hopkins Marine Station. Additional partnerships have included Mexican fishery and oceanographic agencies.

Motivating Factor: Partnerships developed because issues covered huge geographic areas, and expertise existed within a broad base of federal, state, academic and industrial sectors. There was a need to respond to the outcry to do something about declining fisheries.

Products: Predictive capability for sardine and related pelagic fish was developed and disseminated. CalCOFI atlases of the oceanography and productivity of California current was produced. New species reports and life histories of hundreds of species were prepared. Hundreds of administrative and technical reports and peer-reviewed publications ensued.

Impact Or Benefits: Target stock has been protected and is now recovering.
Associated species stocks have been protected and have been recovering. Major understanding was developed regarding long-term changes in fishery stocks and the forces that control them. The program provided the first documents on the impact of El Niño on US fisheries.

Lessons Learned: Fisheries operate on long-term, large scale basis. One organization can't persist with long-term, large scale programs. CalCOFI succumbed to funding cuts in 1970's and suffered a critical data "hole".

Acronyms and Abbreviations

ARPA	Advanced Research Projects Agency
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CIA	Central Intelligence Agency
CNO	Chief of Naval Operations
CORE	Consortium for Oceanographic Research and Education
DOE	Department of Energy
EJIP	Eddy Joint Industry Project
EPA	Environmental Protection Agency
ETF	Environmental Task Force
GOOS	Global Ocean Observing System
IDBMS	Integrated Data Base Management System
IGOSS	Integrated Global Ocean Services System
INO	Institute for Naval Oceanography
IoM	Institute of Medicine
IUSS	Integrated Undersea Surveillance System
JIC	Joint Ice Center
LTER	Long Term Ecosystem Research
MEDEA	Measurement of Earth Data for Environmental Analysis
MMS	Minerals Management Service
NAE	National Academy of Engineering
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCSS	National Council for the Social Studies
NESDIS	National Environmental Satellite, Data, and Information Service
NIC	National Ice Center
NMEA	National Marine Educators Association
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOLC	National Ocean Leadership Council
NODC	National Oceanographic Data Center
NORDA	Naval Oceanographic Research and Development Activity
NOS	National Ocean Service
NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSTA	National Science Teachers Association
OMB	Office of Management and Budget
ONR	Office of Naval Research
OSTP	Office of Science and Technology Policy
ROV	Remotely Operated Vehicle
S&T	Science and Technology
SAR	Synthetic Aperture Radar
TOGA	Tropical Ocean - Global Atmosphere
UCAR	University Corporation for Atmospheric Research
UNOLS	University - National Oceanographic Laboratory System
USACoE	United States Army Corps of Engineers
USCG	United States Coast Guard
USGS	United States Geological Survey

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